Technologies for Water Recycling and Reuse in Latin American Context: Assessment, Decision Tools and Implementable Strategies under an Uncertain Future

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Development and application of a web-based geographical tool for WR&R technologies

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Accronyms

- BOD Biological Oxygen Demand
- COD Chemical Oxygen Demand
- FC Faecal Coliform
- MLSS Mixed Liquor Suspended Solids
- NTU Nephelometric Turbidity Units
- SPMR São Paulo Metropolitan Region
- TC Total Coliforms
- TSS Total Suspended Solids
- TN Total Nitrogen
- TOC Total Organic Carbon
- TP Total Phosphate
- TSS Total Suspended Solids
- WHO World Health Organization
- WWP Waste water production
- WWTP Waste water treatment plant

Executive summary

A tool to support the planning of water reuse schemes in zones at risk of water scarcity
Several Latin-American countries are facing challenges to provide their societies with sufficient water of sufficient quality to support expanding urban areas, irrigated agriculture, and industrial development (UN-Habitat, 2012), (UN, 2014), (Jiménez, 2008). The challenges relate to shrinking available fresh water resources due to more abstraction than can be renewed (van der Bliek, McCornick, & Clarke, 2014), (Yoshihide Wada, van Beek, & Bierkens, 2012)(Yang, Pfister, & Bhaduri, 2013), and to increased wastewater flows from growing cities, industrial and agricultural areas, causing problems with urban sanitation and pollution of the environment (Galli, 2014), (UN, 2014). Water scarcity can also be related to an inter-annual variability in water supply, as reflected in the water scarcity situation experienced by the Sao Paulo Metropolitan area in 2014[1].

Water reuse and recycling technologies (WR&RT) are among the most promising integrated solutions to improve access to water of sufficient quality. In order to support institutions and decision makers working with climate- sensitive projects and investments in water management, the EU-funded COROADO project (www.coroado-project.eu) commissioned Alterra, FHNW and BIOFORSK, in collaboration with the project partners in the case study area in Argentina, Brazil, Chile and Mexico and the other project partners, to develop a web-based geographical tool for stakeholders involved in the planning of water reuse systems. The main goal of the tool is to demonstrate how water management approaches founded on water reuse can be designed and planned in geographical space to promote long-term sustainability and water resilience in the face of climate variability and change. The tool is intended to support the spatial planning of water reuse schemes in zones at risk of water scarcity, and to evaluate options for water reuse. The WP4-tool consists of a set of information products and tools which have been incorporated in the COROADO Decision Support System (http://coroado.tk, to be used with Internet Explorer). The aim of this report is to document these products and tools, and to show results of the application to the four case study sites in Argentina, Brazil, Chile and Mexico, and to a larger extent to the Latin-American continent.

The tool developed in WP4 consists of six modules. Modules 1-3 help the user to identify which parts of the area under consideration (a river basin or region in Latin-America) have lower and higher availability of green and blue water flows based on the characteristics of the physical water system (i.e. climatic conditions, land cover and use, soils, hydrography, relief and substrate), which parts of the area suffer from water stress conditions, and which areas offer potential for water reuse and recycling systems. Modules 4 and 5 enable the user to identify sites where wastewater is currently produced, and the locations of potential users of recycled and treated wastewater in the area. This results in a selection of zones with potential for the implementation of water reuse systems, and identified quantity and quality of treated wastewater in the zone. In Module 6 (POSEIDON), the user can select wastewater treatment technologies to meet the required water quantity and quality of specific water users in the zone. Treatment technologies can be combined into a wastewater treatment train, which can be compared based on economic, ecological and technical criteria. This results in a basket of optional wastewater treatment systems. These options can be further explored in the COROADO DSS using multi-criteria analysis.

Assessment of available blue and green water flows (module 1)
The hydrological model PCRGLOBWB (L.P.H. Van Beek & Bierkens, 2009) (L. P. H. van Beek, Wada, & Bierkens, 2011a) is used in Module 1 of the WP4-tool for the assessment of the available blue and green water flows. In the case study areas. Results from the application of the tool include maps of mean monthly available blue water flows. The maps are available for Latin-America at a resolution of 5 arcminutes (≈10 km), and for the four case study sites in Argentina, Brazil, Chile and Mexico at a resolution of 30 arcseconds (≈1 km) (Figure 2). The maps of blue water availability and the water balance component charts are available for the baseline period 2000-2010 and for 5 scenario situations of future climatic change. For the Latin-American domain, maps are also available for the period 1960-2010. For the case study sites, Module 1 also offers charts of the annual water balance, with information on the shares of precipitation, evapotranspiration, runoff and change in storage in surface, soil and groundwater. The ratio between the components of evapotranspiration and runoff reflects the proportions of green and blue water available for economic and societal use.

[1] http://www.wri.org/blog/2014/11/3-maps-help-explain-s%C3%A3o-paulo-brazil%E2%80%99s-water-crisis

Scenarios of available water and water stress under climate change

The WP4-tool offers the possibility to inspect changes in available water (module 1) and water stress conditions (modules 2 and 3) under scenarios of climate change. These scenarios were constructed based on climate change projections from the WorldClim dataset (www.worldclim.org), generated using outputs from 19 GCMs in combination with the four Representative Concentration Pathways employed in the 5th Assessment Report from the IPCC. In order to include the uncertainty in the different GCMs and RCPs, five different climatic scenarios were chosen among the available 63 different scenarios using a method combining changes in precipitation and temperature from the cumulative density distribution of the scenarios with reference to the historical climate (1950-2000). The five scenarios representing combinations of the 10th and 90th percentile of change in precipitation and temperature were selected for the assessment of available blue and green water in the WP4-tool. The climate change scenarios represent the period centered around 2050 (2041-2060).Increases in precipitation of 12-13% are expected for the case study sites in Brazil and Argentina under the 'wetter' (P90) scenarios. A decrease in precipitation is projected for the case study sites in Brazil, Chile and Mexico under the 'drier' scenarios (P10), by 20-25% for the case study site in Chile, and between 7 and 12% for Brazil and Mexico. Projected increases in temperature in the case study sites are between 0.8 and 1.3 °C in the 'warmer' scenarios (T10), and between 1.9 and 3.0 °C in the 'hotter' scenarios (T90). For demonstration purposes, the results of the baseline scenario were compared to the results of the P10T90 and P90T10 scenarios in the report.

For the Alto Tiete River Basin in Brazil, the P10T90 scenario brings a decrease of potentially available blue water across the basin for all seasons except the period December-February. Areas along the southern border feeding the drinking water reservoirs of Guarapiranga and Billings have relatively high reductions in water availability in the September-November period (20-30%) and the June-August period (50-70%). For the P90T10 scenario, potential water availability increases in the whole catchment, especially in September-November period (with up to 60-90%). Largest increase in potential water availability is projected for the forested areas in the north-western part of the catchment; the smallest (5-20%) in the urbanized areas.

For the Suquia River Basin in Argentina, all scenarios of climate change bring an increase in available blue water in the mountainous upstream part of the catchment, which is a source of surface and groundwater for water users in the downstream part of the basin. A decrease in available water is expected for the central part of the catchment with rainfed agriculture in the period December-February in the P10T90 scenario. Reductions are at most 13% in the P10T10 scenario, and then in the winter, which will not be harmful to the agricultural sector, but possibly for the urban/domestic sector. However, in most simulations and seasons, and in the most areas of the catchment, changes are slightly positive to positive (up to +50%), indicating that potentially available blue water will not be reduced under climate change in this area.

For the Copiapo River Basin in Chile, the hydrological model in the WP4-tool projects a decrease in potential available blue water in all climate change scenarios and in all months. For the scenarios predicting an increase in future precipitation (P90T90 and P90T10), the decrease in potential water availability can be explained by an increase in potential evapotranspiration and the fact that the absolute increase in precipitation is small.

The P10T90 scenario brings a decrease in available blue water across the Lower Rio Grande basin in all seasons. An especially large decrease in water availability (50-70%) is projected for the southern parts of the area with rainfed agriculture. In the seasons covering the growing season (MAM and JJA), only the scenarios with increased precipitation (P90) result in an increase in available blue water (from 15-30%).

The WP4-tool can be used to generate information on the proportion between available green and blue water under various conditions of climate and land use. Green water flow constitutes the larger part of the available fresh water in the areas in Argentina and Chile (resp. 65-70% and 90-100%). In the area in Brazil blue water is the larger part of the available flow (50-62%). Changes in the proportion between green and blue water flows under different scenarios of climate change are marginal; at most 8% in either direction. Considering that the spatial distribution of land use and land cover was kept as in the baseline situation for all scenarios, this indicates that climate change only has a minor influence on the partitioning of green and blue water flows, and that there is scope for improving the use of available green water through soil management and land use change.

For the Latin-American domain, the scenario T90P10 generally produces less discharge compared to the baseline. Some areas have a simulated increase in mean monthly discharge compared to the baseline. This is because projected change in rainfall and temperature will vary geographically. The scenario T10P90 produces more discharge compared to the baseline. A comparison of the model results with the regional projections from the IPCC (AR5 report (IPCC, 2014)) shows that most scenarios (except T90P90) expect less discharge in Central America compared to the reference period, in correspondence with the IPCC report. The decrease in Northern South America according to the (IPCC, 2014) is not so explicit in our scenarios. The Amazonia region shows a lot of variation (some parts show an increasing discharge, others a decreasing discharge) in our scenarios. There seems to be a slight tendency towards decreasing discharge in the Central Andes in our simulations. The Northeast Brazilian (NE) region presents a lot of variation in the simulated discharge. Based on the scenario simulations it is hard to confirm the findings of (IPCC, 2014) for this region. In the wetter scenario simulations (P90) there seems to be an increase in discharge in the Southeastern South American region, in correspondence with the IPCC projections, but in the other scenario simulations the variations within the region are too large to make a clear statement.

Assessment of water demand (module 2)
The WP4-tool includes a tool to map the gross water withdrawal by economic sector in a region or river basin. The Water Demand Assessment Tool consists of a scriptfile, input tables and maps created in the PCRaster Package (http://pcraster.geo.uu.nl/pcraster/4.0.0/doc/manual/secintro.html). The maps indicate the locations of urban and domestic water use, industrial water use, agricultural water use and water use for mining ('water user zones maps'). Lookup tables can be used to enter the annual gross water withdrawal in $m^3.s^{-1}$ per use type from surface water and groundwater.

The Water Demand Assessment Tool uses the observed gross water withdrawal by economic sectors in the region of interest as a proxy for the water demand for various reasons, related to the distance of water supply from source to user, and the variation of water demand between societies, cultures and regions. Gross instead of net water withdrawal is considered for several reasons, a.o.missing information on locations and timing of return flows. The report shows an example application of the Water Demand Assessment Tool to the Mexican case study area. The resulting maps include maps of the annual water withdrawal for urban/domestic and industrial use, and maps of monthly withdrawal for irrigated agriculture, showing the variation of withdrawals in space over the year. A map of total withdrawal from all sectors can be produced.

Water stress assessment (module 3)
The WP4-tool uses a spatially distributed index of water stress for the objective to highlight areas at risk regarding water scarcity and water quality under current and future conditions. The Water Stress Index (WSI) is based on aspects of water quantity and water quality similar to the WTA ratio[2], capable of providing information at a monthly temporal resolution, and capable to integrate climate forcing under current and future conditions. The WSI is based on the relative water demand by water users on a given location in the region (the local relative water demand), and a 'friction-distance' function, that expresses the friction that should be overcome in order to supply available blue water from points of extraction to the locations of water users. The points of extraction or water supply points can be groundwater pumping wells, intake points from rivers and reservoirs, or series of grid cells representing canals with multiple inlets. Differences between the WSI and other indices on water scarcity and water stress reported in the literature are:

- Due to the smaller spatial resolution, the WSI is suitable to consider the spatially explicit location of water user units in a river basin, and can therefore be used to identify zones of water stress within the basin in more detail;
- The WSI takes account of the distance of water user units in the region from actual points of water supply, including groundwater wells, instead of considering only rivers and locally available groundwater as sources of renewable water supply;
- Since the WSI is based on generic characteristics of water systems (local relative water demand and distance from water supply points), it can be used to compare water stress conditions between river basins;
- The WSI considers water supply and water use on a monthly timescale, and can therefore be used to capture seasonal phase shifts in peak water demand and water availability, and to assess frequency and persistence of water stress;

[2] WTA ratio: ratio of total annual withdrawals to available water resources.

- The WSI can take into account other types of friction to the supply from water source to water user, like differences in elevation and differences in water quality.

The calculation of the WSI is integrated in the PCRaster script that is also used for the Water Demand Assessment in module 3. The report illustrates the steps in the application of the modules for water demand assessment (module 2, see chapter 3) and water stress assessment (module 3) in the WP4-tool for the case study area in Argentina. Results of the application to all four case study areas are discussed. A comparison of the maximum catchment-average value of the WSI in the case study areas under baseline conditions and two scenarios of climate change showed that the level of water stress as indicated by the WSI is highest in the Chilean case study area, despite the fact that water users in this area are closer to water supply points than in the other areas. This is caused by the high water demand compared to the low potential blue water availability in this area, if we consider only the renewable water sources. In the case study area in Mexico, the level of water stress is also high compared to the other areas, especially when the minimum blue water availability is considered. This can be explained by the large water demand of the irrigation district DR025, that is located at larger distances from inlets and irrigation channels than irrigated areas in the other study sites. Overall, the level of water stress is slightly higher in the growing period than in the other period of the year due to the demand for irrigation water. This does not apply to the case study area in Brazil, where agricultural water demand is low compared to the demand for urban/domestic and industrial use.

The influence of the climate change scenarios on the level of water stress is small compared to the influence of the variability in potential available blue water within the 10-year periods considered. In the cases where the WSI changes between climate scenarios, WSI is highest in the P10T90 scenario.

The water stress assessment tool also gives information on the spatio-temporal distribution of the WSI in regions. Results of the application to the four case study areas show that significant parts of the 4 case study areas have water stress conditions above the threshold in parts of the year in the baseline situation, especially under conditions of low available water flows. This indicates that water stress caused by high local relative water demands and distance from water supply points is already an issue in the case study areas under current conditions.

The influence of the climate change scenarios on the areas with above-average values of the water stress index (WSI>4) differs between the study sites. In the sites in Argentina and Mexico, the area differs hardly between the baseline and the climate change scenarios. However, in the site in Brazil, the area with WSI>4 increases under both scenarios of climate change compared to the baseline situation. In this area, the scenarios of climate change have a larger influence on the water availabilityl than in the areas in Argentina and Mexico.

The results of the application of the Water Stress Assessment Tool also show a large monthly variation of the areas experiencing water stress in the sites in Argentina and Mexico. This is partly because water demand for irrigation imposes water stress conditions during the growing seasons, and partly due to the seasonal variation of available blue water flows. It is stressed that monthly variations of water demand for other water uses (urban/domestic, industrial, mining) were not included in the set-up of the water stress assessment tool due to a lack of data. Of these water uses, the water demand for urban and domestic use is expected to vary within the year due to seasonal variations in weather conditions. Higher temperatures in the summer will cause an increased demand for water for human consumption, domestic use, cleaning of streets and cars and landscape irrigation in urban areas. Including monthly variations in the water demand for urban/domestic use in the WP4-tool for water stress assessment will increase the area experiencing water stress conditions in the summer months .

The WP4-tool can also generate information on the water stress conditions of different economic sectors using water in the region, and the variation of water stress conditions for each sector over the year. This is done through 'violin plots' and empirical cumulative density functions (ECDFs) of the water stress index, generated by an R- script. The water uses considered include water use for urban and domestic purposes, industry, mines and agriculture. Environmental water requirements were considered for the case study area in Argentina, for which a minimum required river flow was provided. Violin plots and ECDFs are discussed in the report in detail for the case study area in Argentina.

The ECDFs can also be used to derive information on the area of the river basin covered by WSI values of given percentiles for each water using sector, e.g. the 50th percentile. The results can be compared between case study areas, between water using sectors, between flow conditions (10-year mean, minimum and maximum flows) and between climate change scenarios. An analysis of the 50th percentile of the WSI by economic sector for the four case study areas shows that within the water using sector irrigated agriculture, the WSI is highest in the Mexican case study area, with values up to 6.5. The case study areas in Brazil and Mexico have zero values of WSI at the 50th percentile in periods of the year. For the urban and domestic water using sector, WSI values at the 50th percentile are also highest in the Mexican case study area, with values between 4 and 5, compared with values around 4 and 3 for the areas in Argentina and Brazil respectively. This indicates that the water stress conditions as determined by the local relative water demand and distance from water supply points are most severe in the Mexican case study area.

As expected, conditions of minimum available blue water flows over the 10-year period cause the largest values of the WSI, whereas conditions of maximum available flow yield lower values of the WSI. Considering the differences between flow conditions over all case study areas and all water using sectors, variations in the WSI due to flow conditions are largest for the water using sector irrigated agriculture, with up to one unit of change. This indicates that this sector is the most sensitive to annual changes in blue water availability.

Matching wastewater producers and re-users (modules 4 and 5)
The actual production of wastewater in a region is one of the basic information blocks in the spatial planning of water reuse schemes in a region. Modules 4 (Find wastewater producers) and 5 (Find potential reusers) of the WP4-tool consist of guidelines for mapping current wastewater production and potential users of wastewater in regions of Latin-America in seven steps, using a spreadsheet software and a GIS. Application of the tool finally leads to suggestions for potential stakeholders in water reuse schemes, based on their locations in the region and their typical profiles of wastewater production and water use in terms of water quantity and water quality. It should be noted that the method is not suitable for a detailed feasibility analysis for water reuse schemes. For that purpose, advanced tools and methods are available from the literature.

Steps 1 and 2 of the guidelines include the collection and registration of information on water abstraction and wastewater discharge by various actors in the region: municipalities, WWTPs, industries, agricultural areas, mines. Maps created in the next step (step 3) show the spatial distribution of wastewater discharge locations and water users. The map of wastewater discharge locations provide insight in the geographical distribution and magnitudes of wastewater flows produced in the region. In regions where wastewater is only partly collected and treated, like in some countries in Latin-America, such images give insight in the potential for wastewater reuse. The map of water users (step 4) gives insight in the geographical distribution of water users in the region and their water demands, and the current abstractions from different water sources. At a glance it reveals the proportions of abstractions from different sources, e.g. from surface water versus groundwater, and the proportions between abstractions by different economic sectors (e.g. urban/domestic versus agriculture). Existing wastewater reuse schemes in the region must be identified as part of the wastewater producers and reusers, and to highlight possibilities to share treatment facilities and infrastructure (step 5). In step 6 information on wastewater producers and potential reusers is used to calculate wastewater flows that are currently not reused in the region. The water demands from users in the region listed in the spreadsheet allow to find matches with the surplus available wastewater from producers. The final step (7) is the sketching of potential WR&R schemes in a map, connecting wastewater producers and potential reusers identified in the previous step, and collecting information on the characteristics of wastewater discharge and water use by these actors in attribute tables. Such maps can be used in round table sessions for planning water reuse schemes with stakeholders.

The application of the 7-step framework to the four case study areas is documented in separate reports for each case study area in Annex 1.11. The accompanying maps, geoinformation and spreadsheets are available through the COROADO WebGIS from WP3. The reports show that the local situation of wastewater production and water use differs considerably between the case study areas, and that the spatial planning of water reuse schemes requires a local analysis of wastewater producers and water users in their geographical context. The results from the analysis with the 7-step framework should be combined with information on the socio-economic profiles and preferences of these stakeholders (e.g.

economic power, willingness to pay). Such information can be captured by using the COROADO DSS in stakeholder sessions.

Evaluation of Waste Water and Water Reuse options (module 6)
In the COROADO case study sites the need for additional freshwater resources is the main driver for the interest in WR&R schemes, also because WR&R schemes are considered more cost-effective than alternative solutions to obtain additional freshwater resources (new freshwater resources are often located at an important distance and require high pumping and distribution costs). The objective of wastewater recycling and reuse is the treatment of wastewater to a stage of purity that can directly be used for specific purposes. Water reuse has received growing attention with regard to mitigation of water scarcity and as an opportunity to avoid high first-use water prices.

As part of the WP4-tool a system was developed within WP4 of the COROADO project in order to facilitate the selection and evaluation of different options also for non-expert users. This part of the assessment guided by the WP4-tool is termed the 'Stage II assessment'. Modules 1-5 of the WP4-tool form the 'Stage I assessment'.

There are many water reclamation technologies available for primary, secondary and tertiary treatment, as well as for disinfection. Individual technologies are called unit processes (UP). These unit processes usually work in combination commonly referred to as **Treatment Trains (TT)**. For each identified case study with potential for water reuse (resulting e.g. from modules 1-5 in the WP4-tool), there are plenty of feasible combinations of technologies that can meet the required pollutant removal target at the desired treatment cost. In the WP4-tool, a **water reuse option has to be understood as a feasible treatment train** in order to treat the available wastewater to a quality complying with the intended use.

The system developed for the WP4-tool contains a list of treatment trains with characteristics, such as technical performance on pollutant removals, several evaluation criteria, requirements and impacts, as well as a quantitative cost module to estimate the foreseen costs of treatments. The system calculates which of those treatment trains would comply with the requirements defined by the user and present the best options to the non-expert user based on the different characteristics defined before.

The main objective of the stage II assessment is to **promote water reuse** and to show that several treatment trains can achieve the requirements to match the supply and demand of wastewater in the zones at risk of water scarcity identified within Stage I. The evaluation system also contains a wide range of content, descriptions, figures and resources and can therefore also be used for capacity building purposes. The assessment should be considered as a pre-feasibility study, where options are proposed and can be compared. This should lead to awareness raising of users and stakeholders addressed by this assessment on the potential of water reuse compared, for example, to the exploitation of new water sources. However, the system should not be seen as a design support system. For further in-depth feasibility studies and design of treatment trains, there are more sophisticated models available, and the intervention of experts, engineers and planners is normally mandatory.

The system developed in WP4 is intended to cover a very broad range of scenarios for water reuse and the results is understandable by a wide range of users, also non-experts. However, the reality involved for the real implementation of a water reuse scheme implies additional local specificities and technical information details that cannot be included in a system as holistic as the stage II assessment. The results obtained should therefore always be considered with a pinch of salt, mostly because of resulting uncertainties.

The system for the stage II assessment has been integrated within the COROADO online Decision Support System (DSS)[3]. Deliverable 4.2 presents all the background information required for the integration within the online DSS (chapter 6). In parallel, an Excel file named "Poseidon" is under development for individual use, and will be delivered additionally to Deliverable 4.2.

The starting point for the evaluation of water reuse options in the WP4-tool is the end of the assessment from modules 1-5 in WP4 (also termed 'Stage I assessment'). The following information should be available:

[3] Available at the website: www.coroado.tk to be used with Internet Explorer

- Available water to be reused (quality, quantity and location)
- Intended reuse(s) (quality and quantity required, location)
- Community profile composed of several locally-specific information (e.g. electricity costs, labor cost, water tariff)
- Several scenarios to be analyzed

For each scenario to analyze and based on the input data provided, the system will calculate several parameters: the pollutant removal performance of every treatment train included in the system, the lifecycle treatment costs and evaluation criteria. Based on that information, the stage II assessment proposes an evaluation algorithm that calculates the 3 best candidates. The algorithm proposes three different evaluation methodologies to select the three best candidates within the list. The first possibility (1) eliminates all treatment trains that do not comply with the quality requirements (based on the maximal removal performance of each unit process). Then, a ranking is made based on the weights for each single indicator defined by the user. The second possibility (2) first eliminates all treatment trains that do not comply with the required quality and then rank the three options with the lowest lifecycle treatment costs calculated. The user can then evaluate the three options by analyzing the whole set of evaluation criteria calculated. The third possibility (3) is primarily intended for experts and allows a manual selection of the best options based on a subjective evaluation of all evaluation criteria presented.

The details of the methodology applied and calculation involved are presented in chapter 6. Information on water quality classes, unit processes, treatment trains, cost estimations and water quality standards is documented in chapter 6.

1 Introduction

Several Latin-American countries are facing challenges to provide their societies with sufficient water of sufficient quality to support expanding urban areas, irrigated agriculture, and industrial development (UN-Habitat, 2012), (UN, 2014), (Jiménez, 2008). The challenges relate to shrinking available fresh water resources due to more abstraction than can be renewed (van der Bliek et al., 2014), (Yoshihide Wada et al., 2012)(Yang et al., 2013), and to increased wastewater flows from growing cities, industrial and agricultural areas, causing problems with urban sanitation and pollution of the environment (Galli, 2014), (UN, 2014). Water scarcity can also be related to an inter-annual variability in water supply, as reflected in the water scarcity situation experienced by the Sao Paulo Metropolitan area in 2014[4].

In several countries in Latin-America, infrastructure for wastewater collection and treatment is absent or deficient (Urkiaga et al., 2006), (FAO, 2014). Poor water conditions in Latin-America call for urgent solutions, if emerging impacts on human well-being and the environment are to be constrained. Climate change and climate variability are expected to aggravate the aforementioned problems, due to impacts on both water supply and demand (IPCC, 2014),(Ligtvoet & Hilderink, 2014), (UN, 2014). Climate variability and change is an exacerbating challenging factor for water resources governance and management, and a key uncertain factor in planned investments (García et al., 2014) (Falkenmark & Rockström, 2010a).



Water reuse and recycling technologies (WR&RT) are among the most promising integrated solutions to improve access to water, and can be an alternative to abstracting new water sources as they perform two fundamental functions (Urkiaga et al., 2006),(Wintgens & Hochstrat, 2006): the treated effluent is used as a water resource for beneficial purposes, and the effluent is kept out of receiving environments like streams, lakes, soils, flora and fauna, thus reducing pollution of these environments and health impacts on biota. An inventory of current approaches of reuse and recycling technologies in four Latin-American countries in the framework of the EU-funded COROADO project showed that both functions of WR&RT are primary incentives for an interest to implement water reuse schemes in the areas (Verzandvoort et al., 2013). Only part of the wastewater produced in the four case study sites is collected and treated (33-65%), which indicates a high potential of water reuse and recycling schemes to employ wastewater as an alternative water resource. The study confirmed that the direct and intentional water reuse is still marginal in all sites: reclaimed water is still less than 5% of the total water demand.

In order to support institutions and decision makers working with climate- sensitive projects and investments in water management, the EU-funded COROADO project (www.coroado-project.eu) commissioned Alterra, FHNW and BIOFORSK, in collaboration with the project partners in the case study area in Argentina, Brazil, Chile and Mexico and the other project partners, to develop a web-based geographical tool for stakeholders involved in the planning of water reuse systems. The main goal of the tool is to demonstrate how water management approaches founded on water reuse can be designed and planned in geographical space to promote long-term sustainability in the face of climate variability and change. The tool is intended to support the spatial planning of water reuse schemes in zones at risk of water scarcity, and to evaluate options for water reuse. The assessment should be considered as a pre-feasibility study, where options are proposed and can be compared. This should lead to awareness raising of users and stakeholders on the potential of water reuse compared, for example, to the exploitation of new water sources. However, the tool should not be seen as a design support system. For further in-depth feasibility studies on the hydrology of the areas and the design of treatment trains, there are more sophisticated models available (e.g. (Hamouda, Anderson, & Huck, 2009), (Suárez et al., 2014) and the intervention of experts, engineers and planners is normally mandatory.

[4] http://www.wri.org/blog/2014/11/3-maps-help-explain-s%C3%A3o-paulo-brazil%E2%80%99s-water-crisis

The terms of reference for the tool state the following requirements:

- Promoting water reuse as a potential solution to improving access to water, providing alternative fresh water resources, and reducing environmental pollution;
- highlighting areas at risk regarding water scarcity and water quality under current and future conditions, and
- providing a basket of options for selection of additional water treatment and water reuse technologies to address future needs.

The tool, henceforth referred to as 'the WP4-tool', consists of a set of information products and tools which have been incorporated in the COROADO Decision Support System (http://coroado.tk, to be used with Internet Explorer). The aim of this report is to document these products and tools, and to show results of the application to the four case study sites in Argentina, Brazil, Chile and Mexico, and to a larger extent to the Latin-American continent.

Concept of the WP4-tool

The tool developed in WP4 consists of six modules (Figure 1). The first three help the user to identify which parts of the area under consideration (a river basin or region in Latin-America) suffer from water stress conditions, and which areas offer potential for water reuse and recycling systems. This part of the tool offers geographical background information on the area, like topography, climate, land use and potential available blue[5] and green water[6]. Modules 4 and 5 enable the user to identify sites where wastewater is currently produced, and the locations of potential users of recycled and treated wastewater in the area. This results in a selection of zones with potential for the implementation of water reuse systems, and identified quantity and quality of treated wastewater in the zone. In the last module, the user can select wastewater treatment technologies to meet the required water quantity and quality of specific water users in the zone. Treatment technologies can be combined into a wastewater treatment train, which can be compared based on economic, ecological and technical criteria. This results in a basket of optional wastewater treatment systems. These options can be further explored in the COROADO DSS using multi-criteria analysis.

The six modules are briefly described below, and in more detailed in the following chapters of the report:

Chapter 2: Blue-green Water Availability in the Region (Module 1)
Chapter 3: Water demand assessment (Module 2)
Chapter 4: Water stress assessment (Module 3)
Chapter 5: Matching wastewater producers and re-users (Modules 4 and 5)
Chapter 6: Evaluation of Wastewater and Water Reuse options (Module 6)

[5] Potential available blue water is defined in the WP4-tool as the available blue water flow without considering abstractions. Blue water availability is defined as natural run-off (through groundwater and rivers) minus environmental flow requirements, following (Hoekstra, Chapagain, Aldaya, & Mekonnen, n.d.). Blue water availability typically varies within the year and also from year to year.
[6] Green water is the rainfall that infiltrates in the upper unsaturated soil layers and flows back to the atmosphere as vapor or evapotranspiration (Falkenmark & Rockström, 2010b).

Figure 1. Modules of the web-based geographical tool for water reuse in Latin-America with a short description of their functionality.

In **module 1** the user can assess the availability of blue and green water in the region by inspecting maps of the potential blue water availability, averaged per month or per season, and maps of the annual actual evapotranspiration. These maps were produced using the hydrological model PCRGLOBWB (version 1.1) (L. P. H. van Beek, Wada, & Bierkens, 2011b). This gives insight in which parts of the region blue and green water is available based on the biophysical characteristics of the region (climate, soils, land use), and in which parts there is less water available. The maps are available for Latin-America at a resolution of 5 arcminutes (≈10 km), and for the four case study sites in Argentina, Brazil, Chile and Mexico at a resolution of 30 arcseconds (≈1 km) (Figure 2). For the case study sites, Module 1 also offers charts of the annual water balance, with information on the shares of precipitation, evapotranspiration, runoff and change in storage in surface, soil and groundwater. The ratio between the components of evapotranspiration and runoff reflects the proportions of green and blue water available for economic and societal use.

The maps of blue water availability and the water balance component charts are available for the baseline period 2000-2010 and for 5 scenario situations of future climatic change. For the Latin-American domain, maps are also available for the period 1960-2010. The scenarios of future climate and the potential blue water availability for these scenarios are described in chapter 2.5.

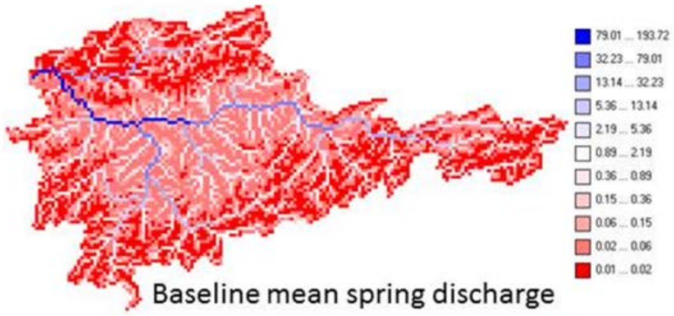

Figure 2 Example of Module 1: average potential blue water availability (in m3.s-1) in the case study area in Brazil in spring, over the period (2000-2010).

In **module 2**, the user can inspect the current[7] spatial distribution of water users and their demands in the four case study sites, on raster maps at a resolution of 30 arcsecs (≈ 1km), where water users are plotted according to the coverage of urban areas, industries and irrigated agricultural areas (Figure 3). Vector maps are also available, where the locations of water users are indicated by points. In both cases, the water demand from users is approximated by the current withdrawal for the different sectors (urban/domestic, agriculture, industry). Using the Water Demand Assessment Tool, the user is able to modify the water demands by different water using sectors, and sub-units of these sectors at specific locations in the region or basin.

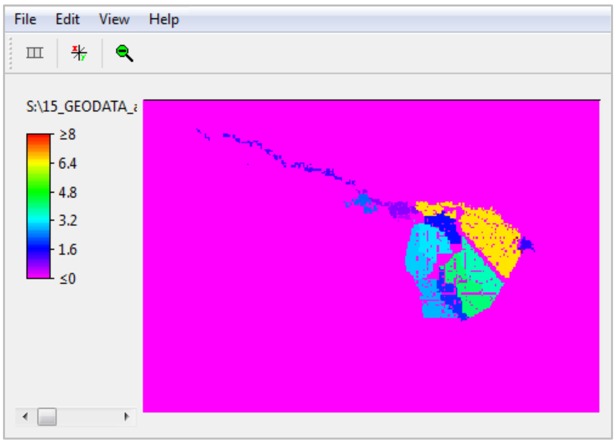

Figure 3 Example of Module 2: map of annual total water demand (m3.s-1) for urban/domestic use, industrial use and agricultural use in the Mexican case study site.

In **module 3**, the user can confront the maps of potential blue water availability and water demand to obtain a map of the water stress index (WSI) in various months of the year (Figure 4).
The water stress index indicates conditions of water stress as a result of 3 factors: the summed domestic, industrial and agricultural water demand (in volume per time unit) in a given location (from module 2), the potential blue water availability in that location (the locally generated discharge including discharge from upstream cells) (from module 1), and the distance from supply points to water users. The water stress index considers demand from blue water sources for urban/domestic use, industry, mining and irrigation. Green water is withdrawn from the soil or directly from the atmosphere by agricultural land use types and planted or natural vegetation, and is therefore not included in the water stress index. The index is meant to identify zones with blue water scarcity. The water stress index maps are available for existing conditions (baseline period 2000-2010) and for the 5 scenarios of climatic change.
Water stress conditions not only depend on available water to meet the water demand, but very importantly by the quality of the available water (e.g. (Cmy, 2006), (Chang, Yang, Goodrich, & Daranpob, 2010). In the COROADO project, insufficient information was available on water quality and its spatial distribution in the case study sites to include water quality as a criterion in the water stress index.

[7] Conditions referred to as ‘current’ in this report refer to the most recent year for which information on water withdrawal was provided by the study site teams. This year varies from 2010-2012.

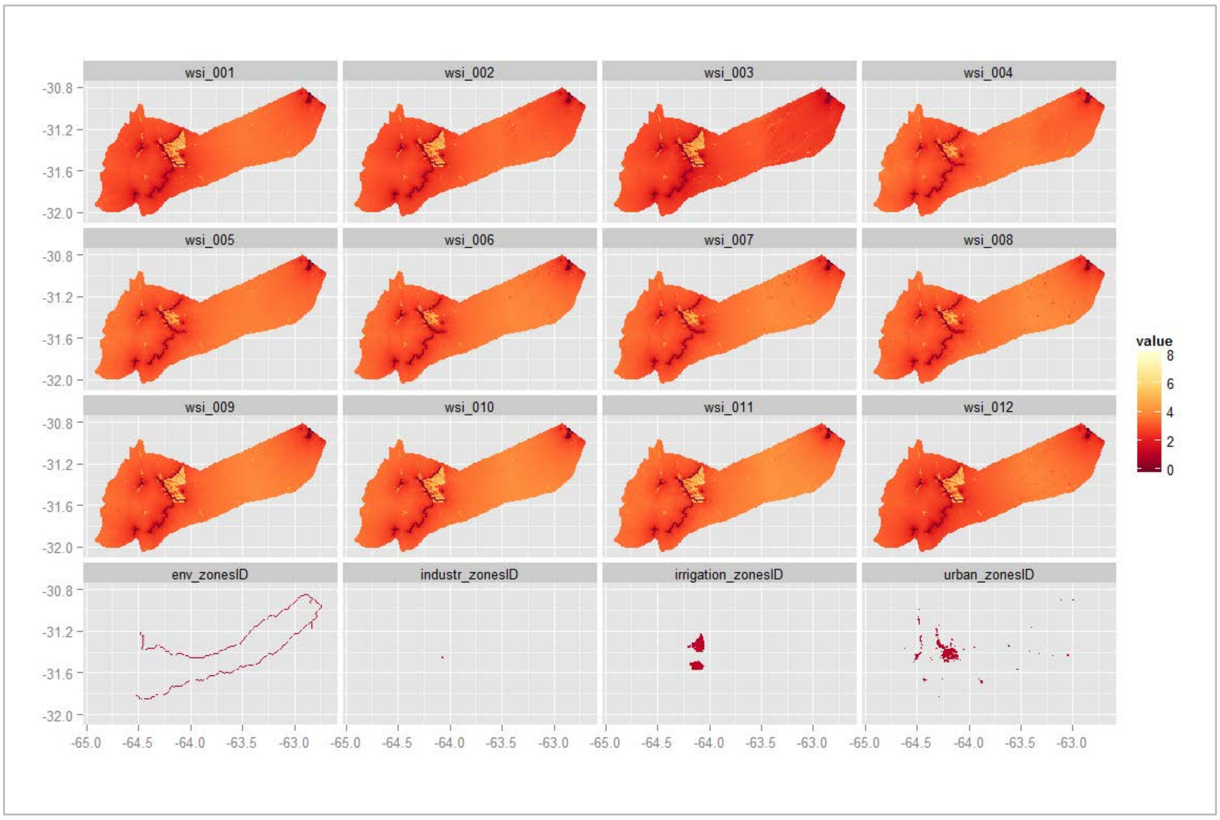

Figure 4 Monthly Water Stress Index (WSI) maps of Suquía River Basin, based on minimum (a), mean (b) and maximum (c) potential blue water availability over the period 2000-2010 (baseline conditions). Numbers refer to the months of the year: 001: January, 012: December. The lowest row of maps in each figure represents the water user zones; from left to right: zones of water use for environmental purposes, industrial zones, irrigation zones and urban zones.
Modules 4 and 5 **provide a method to map the locations within a region where wastewater is currently produced, and locations of water users with potential to reuse the wastewater (**

Figure 5). The criteria to match wastewater producers and 're-users' include the characteristics of the produced wastewater (quality and quantity), the requirements of the potential re-users, and the distance between locations of production and reuse.

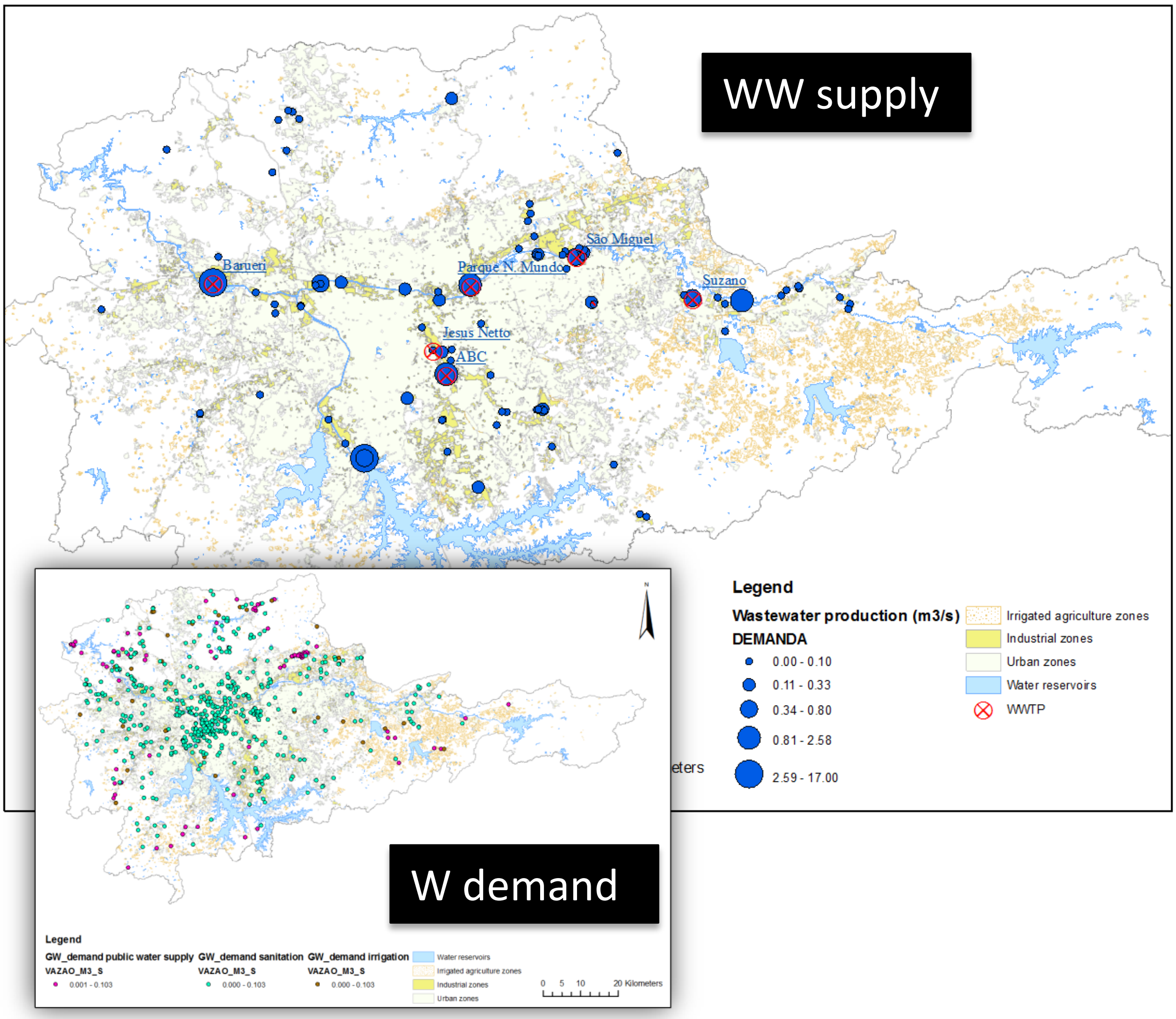

Figure 5 Example of Modules 4 and 5. Left: wastewater discharge locations from urban and industrial sources in the SPMR. Right: distribution of water demand locations from surface water bodies by different sectors in the SPMR, according to permits. Source: water discharge permits from DAEE (2009).

Once the user of the WP4-tool has identified zones under water stress, where wastewater is available and potential re-users occur, he can compile chains of water treatment technologies using the tool from **module 6**, named POSEIDON. This tool helps the user to select and chain water treatment technologies based on characteristics of the available wastewater and the required quantity and quality of the party interested in reusing the water. Module 6 allows the user to compare different water treatment technology trains with regard to pollutant removal performance, lifecycle treatment costs and several evaluation critera (Figure 6). Based on this comparison, the user can compile a basket of options that can be further evaluated in a multi-criteria analysis in the COROADO DSS.

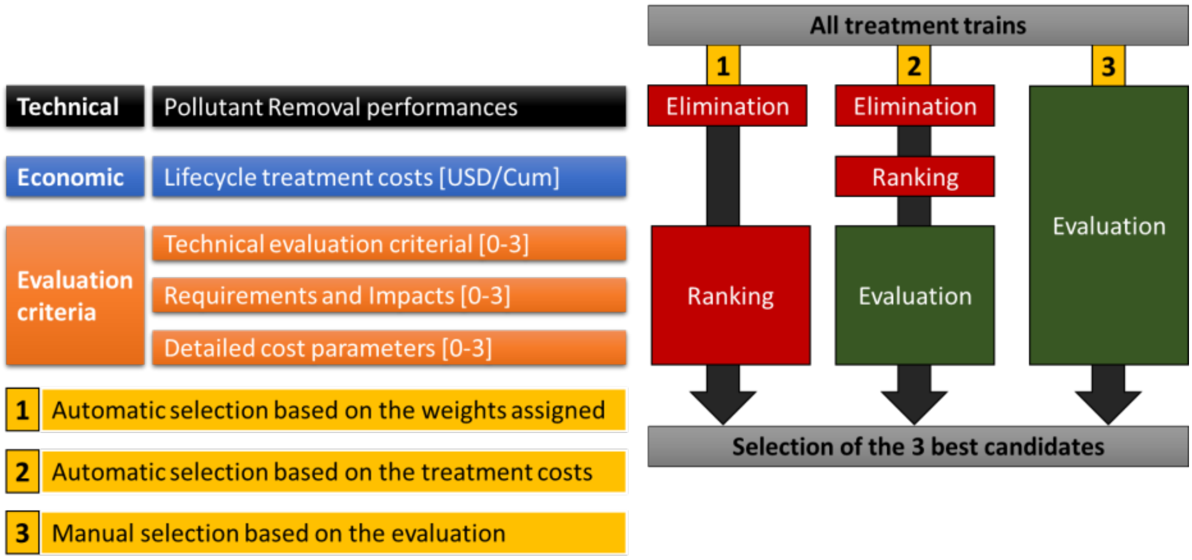

Figure 6 Evaluation algorithm of Module 6.

2 Assessment of blue and green water availability (Module 1)

One of the purposes of the WP4-tool is to highlight areas at risk regarding water scarcity and water quality under current and future conditions, within regions in Latin-America of the size of the COROADO study sites (8000-20.000 km^2). The tool supports this assessment by highlighting areas with lower and higher blue water availability based on the characteristics of the physical water system (i.e. climatic conditions, land cover and use, soils, hydrography, relief and substrate), using the hydrological model PCRGLOBWB (L.P.H. Van Beek & Bierkens, 2009) (L. P. H. van Beek et al., 2011a). When the information on blue and green water availability is combined with spatial information on water demand or actual water withdrawal, and with spatial information on factors that impose friction to fresh water supply to water using units (like slope gradient, distance, energy cost, transport cost), spatial visualizations can be made of zones with water scarcity. Further on in the analysis, modules 4, 5 and 6 allow the evaluation of water reuse schemes as alternative fresh water resources to water users.

Using a hydrological model to assess the spatial and temporal variations in blue and green water availability in regions has several advantages. Although data are often available on current water availability in administrative regions, there is little information on the spatial variation of water availability, nor on the monthly variation in available flows. The PCRGLOBWB model is able to simulate the spatial variability of evapotranspiration, available blue water flow in rivers, reservoirs, soil and groundwater, and its variation through the year. Another advantage of using a hydrological model as part of the COROADO DSS is that water availability under future scenarios of global change can be simulated, such as changes in climate, demography, economy, water demand and land use.

Tools for highlighting areas at risk due to insufficient water quality for required use could not be constructed in WP4 due to insufficient information on the water quality in the blue water resources of the areas under existing conditions. However, the WP4-tool provides information on the water quality standards and norms in the case study areas, as part of POSEIDON (Module 6, chapter 6).

2.1 The PCRGLOBWB model

The hydrological model used for blue water availability assessment in module 1 of the WP4-tool is the PCRGLOBWB model, version 1.0 (www.globalhydrology.nl/models/PCRGLOBWB-1-0/, (L. P. H. van Beek et al., 2011a). It was equipped in module 1 to provide assessments on two spatial domains: the local domain of the 4 case study areas, at a spatial resolution of 30 arcseconds, and the regional domain of water systems in Latin America, at a spatial resolution of 5 arcminutes (Figure 7). PCRGLOBWB is a large-scale hydrological model intended for global and regional studies, developed since 2008 at the Department of Physical Geography of the University of Utrecht, The Netherlands. Prof. Rens van Beek from the Department of Physical Geography of the University of Utrecht provided support for the configuration, set-up and application of the model in the framework of the WP4-tool, and put to the disposal of the COROADO project various input datasets for Latin-America. The model was verified with runoff data in various studies at the global and regional level (L.P.H. Van Beek & Bierkens, 2009), (L. P. H. van Beek et al., 2011b), (Yoshihide Wada et al., 2011), (Y. Wada, van Beek, & Bierkens, 2011), (Y Wada, Beek, & Bierkens, 2011), (Yoshihide Wada et al., 2012), (Candogan Yossef, van Beek, Kwadijk, & Bierkens, 2012), (de Graaf, van Beek, Wada, & Bierkens, 2014). A detailed description of the model is available in (L.P.H. Van Beek & Bierkens, 2009) and (L. P. H. van Beek et al., 2011b). In this report, a brief outline of the model is given.

Figure 7. Spatial domains for blue water availability assessment: the COROADO case study areas (local domain, left) and Latin-America (regional domain, right).

PCRGLOBWB simulates hydrological processes in grid cells representing three vertically stacked soil layers on a daily basis (Figure 8). The water exchange between the soil layers and the atmosphere is simulated through precipitation, evapotranspiration and snow accumulation and melt, which are modified by the presence of the canopy and snow cover. The water exchange between the soil layers and the groundwater is simulated by the model as deep percolation and capillary rise. Variability in properties of the land cover, freshwater resources (rivers, lakes and reservoirs) and the substrate within grid cells is represented in cell fractions. River discharge is calculated by accumulating and routing specific runoff along the drainage network using the kinematic wave approximation, dynamic inundation of floodplains and a reservoir scheme. Channel geometry was configured to calculate evaporation from open water surfaces (in the areas in Argentina, Brazil and Mexico; Chile has no permanent channel flow). Lateral flows between cells consist of overland flow, interflow and baseflow (Figure 8). These three flows comprise the available blue water flows reported in module 1 of the WP4-tool. The flows are aggregated at a monthly level for the purposes of the COROADO-DSS.

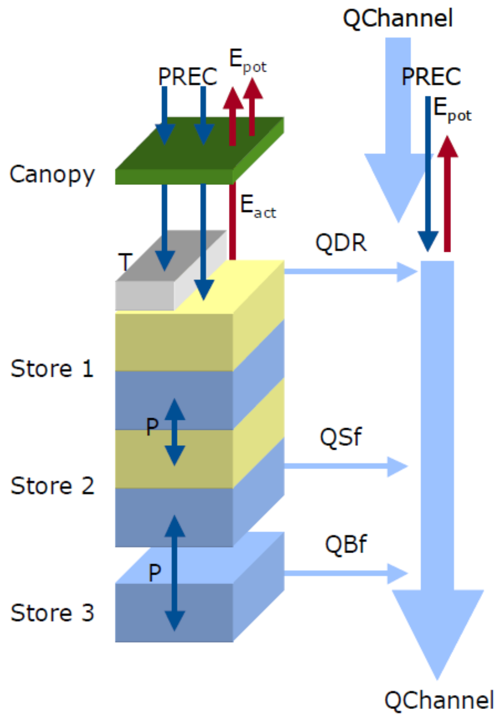

Figure 8. Model concept of PCRGLOBWB: on the left, the soil compartment, divided in the two upper soil stores and the third groundwater store and their corresponding drainage components of direct runoff (QDR), interflow (QSf) and base flow (QBf). On the right the resulting discharge along the channel (QChannel) with lateral in- and outflow and local gains and losses are depicted. Source: (L.P.H. Van Beek & Bierkens, 2009).

2.2 Model configuration and set-up

The PCRGLOBWB model was configured in the WP4-tool with the aim to provide estimates of the blue water availability in regions of the size of the case study areas (local domain) and at the level of the entire river basin in any hydrological system in Latin-America (regional domain). For this purpose, the set-up, configuration and application of the model should not be too laborious and data demanding, and should preferably not require model calibration. The PCRGLOBWB model complies with these requirements, since it is fully parameterized with freely accessible international input datasets, both for the static input on land cover, terrain, substrate and hydrography, as well as for the climate forcing. A thorough model validation was performed by (L. P. H. van Beek et al., 2011a).

The input data used for the set-up of the model for the local and regional domains are listed in Annex 1.1. The climate forcing for the PCRGLOBWB model was obtained from monthly values of precipitation, temperature and reference potential evapotranspiration in the CRU TS 2.1 dataset (New, Hulme, & Jones, 1999), (New, Hulme, & Jones, 2000). These values were subsequently broken down to daily values using the ECMWF ERA-40 and ERA-Interim reanalyses (Kallberg et al., 2005). Climate forcing for five future climate scenarios for the period 2040-2050 was developed for the WP4-tool (chapter 2.5).

Using these input datasets, The PCRGLOBWB model was applied to the case study areas and to the Latin-American domain. The results of these applications are described in chapter 2.3 (local domain) and chapter 2.4 (regional domain). Results for the local domain were compared to annual statistics from literature or data from the case study sites on discharge in streams, release rates at the locations of reservoir dams, and recharge rates of groundwater to provide a basic verification of the model at the scale of the study regions. Since consumptive water abstractions were only partly simulated in the model (in the form of evapotranspiration in irrigated areas), the model results on green and blue water availability should be interpreted as potentially available water.

2.3 Assessment of blue and green water availability under baseline conditions: local domain

This chapter describes the PCRGLOBWB model results as simulated for the river basins in the study areas of the COROADO project. These river basins are the Suquía river basin in Argentina, the Upper Tiête river basin in Brazil, the Lower Rio Bravo/Rio Grande in Mexico, and the Copiapó river basin in Chile.

Except for the area in Mexico, all study areas could be modeled as a hydrological river basin. The area in Mexico receives multiple inflows of water along its borders, since it is bordered on the north by the Rio Bravo/Rio Grande and elsewhere by the borders of Taumapilas State, which are not hydrologically confined. The basin receives water from the Falcon Reservoir at the north-western corner. This inflow was configured in the model using daily timeseries of the observed inflow from the reservoir into the Lower Rio Grande/Rio Bravo. The basin drains along its eastern border into the Laguna Madre, and therefore a single artificial outlet was created to calculate the water balance components for the area.

The model outputs refer to the period 2000-2010, and consist of annual water balance components (precipitation, evapotranspiration, runoff and change in storage). For the case study areas in Argentina and Mexico mean annual and monthly available blue water flows were reported as an illustration of the application of the hydrological model to report timeseries at point locations of interest to water resources management.

Suquía River Basin, Argentina

Figure 9 shows the water balance components for the Suquía river basin simulated by the PCRGLOBWB model for the years 2000-2010. Evapotranspiration (503-642 mm y^{-1}) constitutes the largest component of the water balance. Total discharge is between 170 and 337 mm y^{-1}. The change in total storage is the smallest component, with absolute values between 14 and 95 mm y^{-1}.

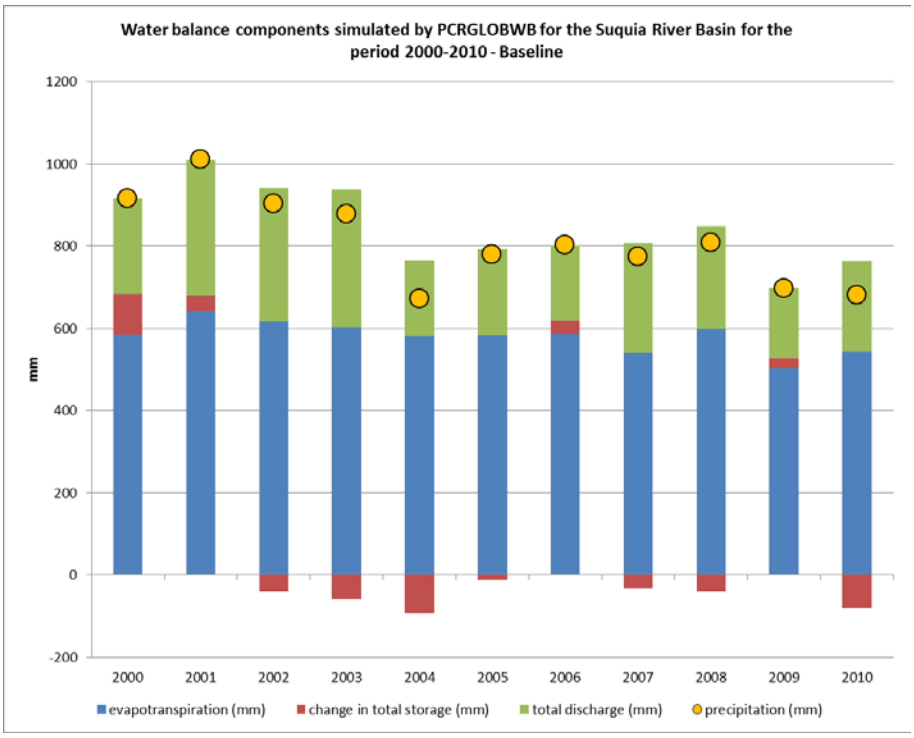

Figure 9. Water balance components for the Suquía River Basin.

Note that the change in total storage represents the water depth, which is stored in or retrieved from the three river basin stores (top layer, soil layer and groundwater layer) on top of the already available water in these stores. The discharge responds to the changes in precipitation between years, with higher discharge in the years with higher precipitation.

Four water supply points of interest were defined for the Suquía River Basin: the dams at the outlets of the San Roque and Los Molinos reservoirs, which provide water for Cordoba city, the Mal Paso Dike and the entrance of the Los Molinos canal (Figure 10). Available water at all four points determines the amounts of water that can be allocated to urban domestic use by the city of Cordóba and other urban areas, and to irrigated agriculture. Supply locations for the industry were not included, since these were not known, and since water use for industrial purposes is small compared to urban/domestic and agricultural use (Verzandvoort et al., 2013).

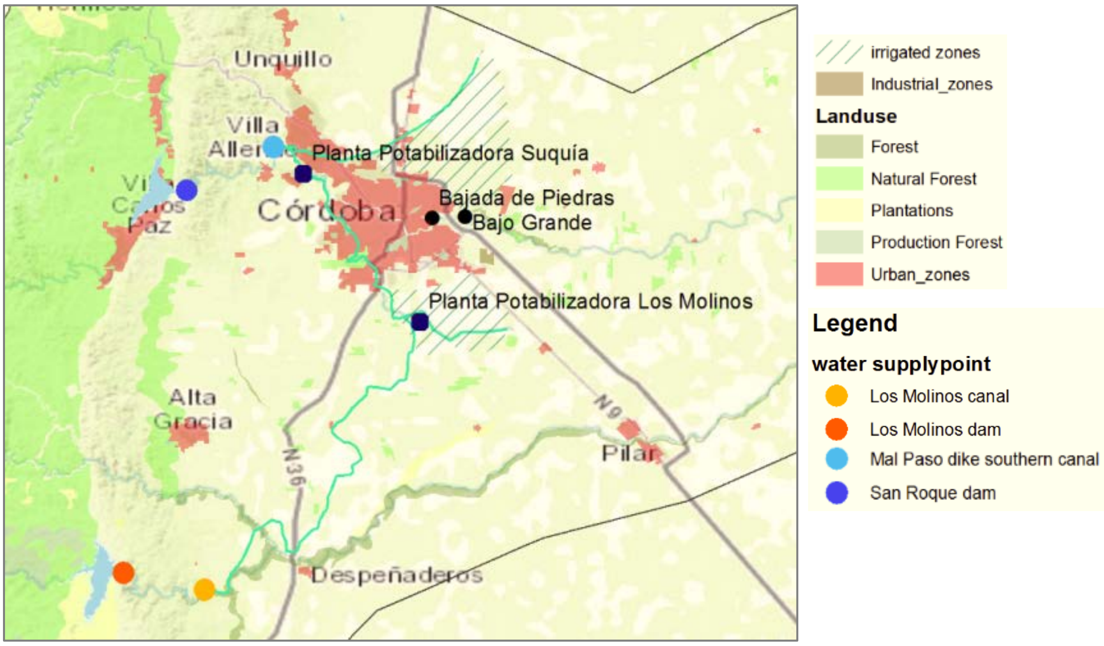

Figure 10. Water supply points in the Suquía River Basin.

The simulated mean annual available blue water flows at the water supply points in the Suquía River Basin are presented in Figure 11. The mean annual discharge at San Roque dam (9.1 $m^3.s^{-1}$) compares well to the mean annual historical discharge of the Suquía River at the San Roque measurement station reported by Pasquini et al. (2006) (in: Pasquini et al., 2012). Cossavella (2013) reported a similar value for the average release rate at the San Roque dam of 10 $m^3.s^{-1}$.

Simulated mean annual discharge varied between 7.1 and 11.6 $m^3.s^{-1}$ over the period 2000-2010, corresponding to a coefficient of variation of 19%. The model results show that the mean annual discharge from the river basin responds to the decrease in annual precipitation between 2003 and 2004 (from 878 to 671 mm), and only recovers after 2006. This shows that the river basin upstream of the San Roque reservoir responds to changes in precipitation input over periods of more than a year. At Mal Paso Dike, the mean annual discharge is a little higher (12.3 $m^3.s^{-1}$) due to inflows received from the contributing area between the two water supply points. The simulated mean annual discharge at Los Molinos Dam and the entrance of the Los Molinos Canal is respectively 6.2 $m^3.s^{-1}$and 7.1 $m^3.s^{-1}$. Variations between years are similar to those simulated at the San Roque Dam and Mal Paso Dike, with coefficients of variation of 19 and 18%. The available water at the Los Molinos Dam is lower than the release rate reported by (Cossavella, 2013)(9.5 $m^3.s^{-1}$). However, this estimate may be too high, considering that the reported inflows by the four contributing rivers to the Los Molinos resevoirs sum up to 8.5 $m3.s^{-1}$. The Los Molinos canal was designed to supply 12 $m^3.s^{-1}$. It only receives water from the Los Molinos river, since the envisaged connection to the Anisacata river is not completed (Tosselli, 2013). The current average flow is estimated at 3.5-4 $m^3.s^{-1}$, about half of the simulated average available water flow at the entrance of the canal in the Los Molinos river. From this flow, about 2 $m^3.s^{-1}$ is taken in by the drinking water purification plant of Los Molinos, and 1.5 $m^3.s^{-1}$ is used to supply the irrigation area south of Cordóba (Tosselli, 2013). Information about the intake from the Los Molinos river into the canal is not available, and therefore the simulated available water at the entrance of the canal cannot be verified. However, it is known that a lot of water infiltrates through the bottom of the channel (Santiago Reyna, pers. comm.).

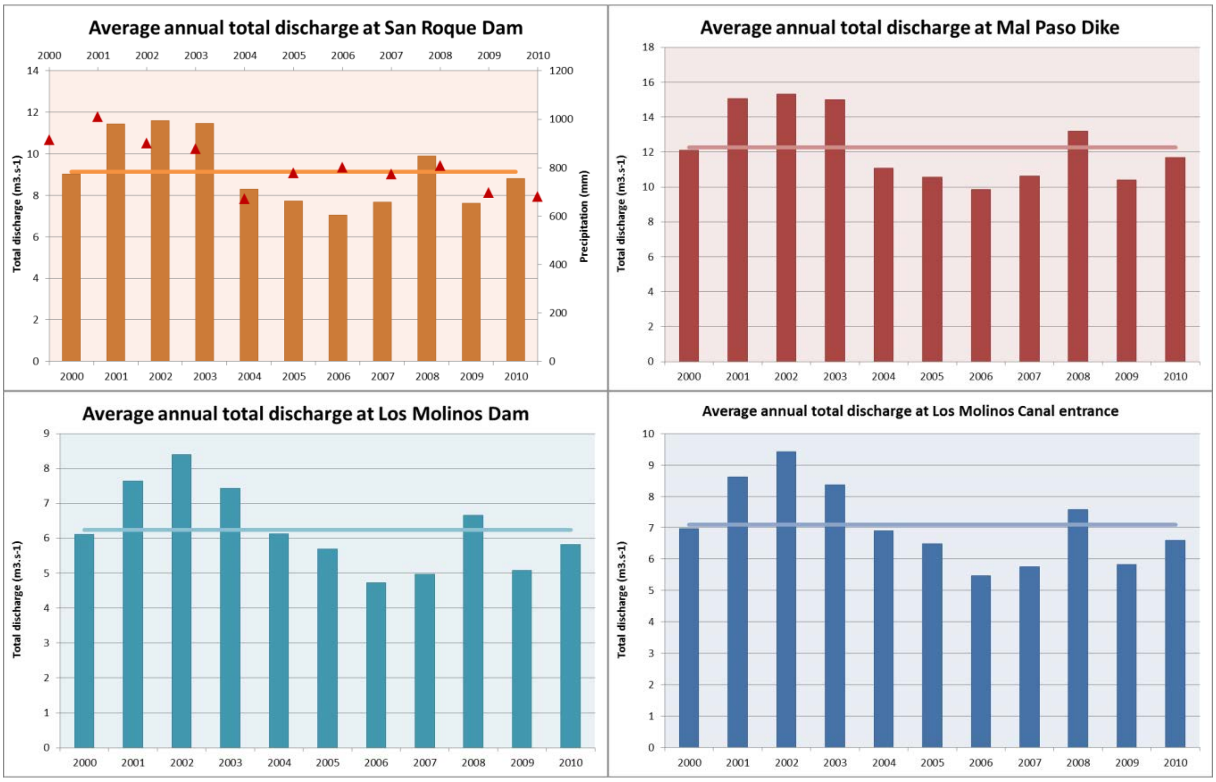

Figure 11. Average annual available blue water flow at different locations in Argentina. Precipitation in triangle symbols (red). Note the different values on the Y-axes.

Alto Tiête River Basin, Brazil

The water balance components for the Alto Tiête river basin as simulated by the PCRGLOBWB model for the years 2000-2010 are shown in Figure 12. Precipitation depths in the first 8 years are between 1600-1700 mm, with the last two years slightly higher; 2009 being the wettest year (2100 mm) and 2010 with 1900 mm.

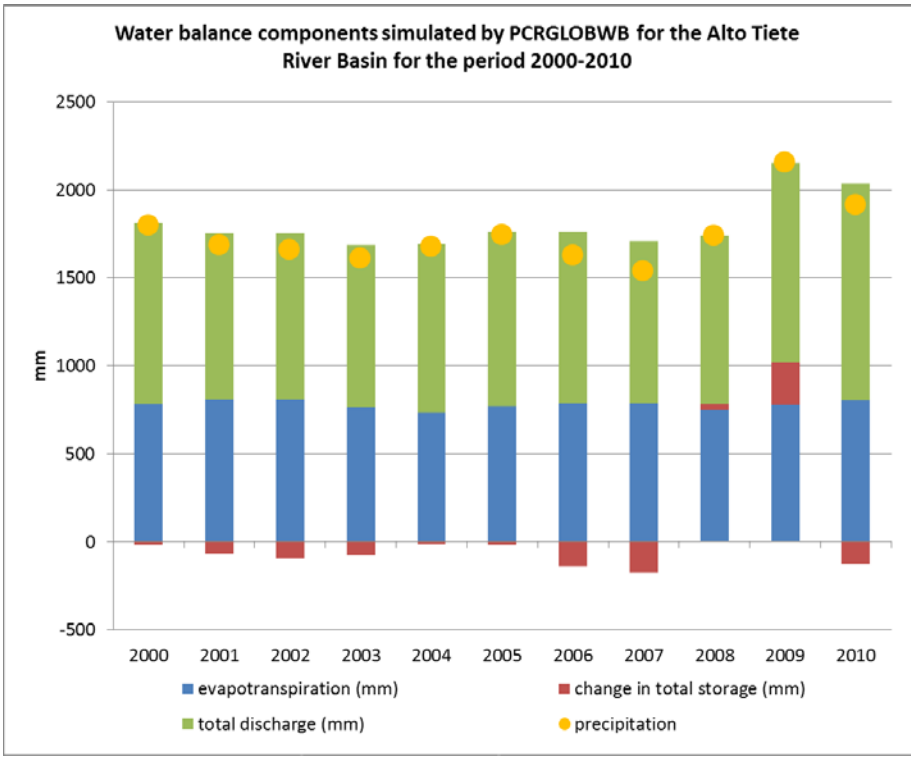

Figure 12. Water balance components for the Alto Tiête river basin, Brazil.

Discharge is the largest outflow in the water balance, with values between 700 and 1000 mm on an annual basis. This can be caused by the land cover in the basin, which is for more than 90% built-up land, with lower permeability and soil water storage capacities than the other land cover types in the basin. During high intensity precipitation episodes these urban areas can experience events of high flashy runoff episodes, that might be less visible at a monthly or annual temporal resolution. The change in storage in the basin is negative in most years, except for the year 2009, as a result of the relatively high precipitation in that year.

Copiapó River Basin, Chile

For the Copiapó river basin in Chile, the PCRGLOBWB model simulations show that the precipitation is almost completely transferred to evapotranspiration, mostly soil evaporation, since the vegetation cover in the catchment is very low (<20%). The simulated precipitation (33-114 mm over the period) is within the band of variation of the precipitation reported for the study area in (Porto et al., 2012) and (Porto & Dalcanale, 2014) (20-500 mm.y^{-1}).

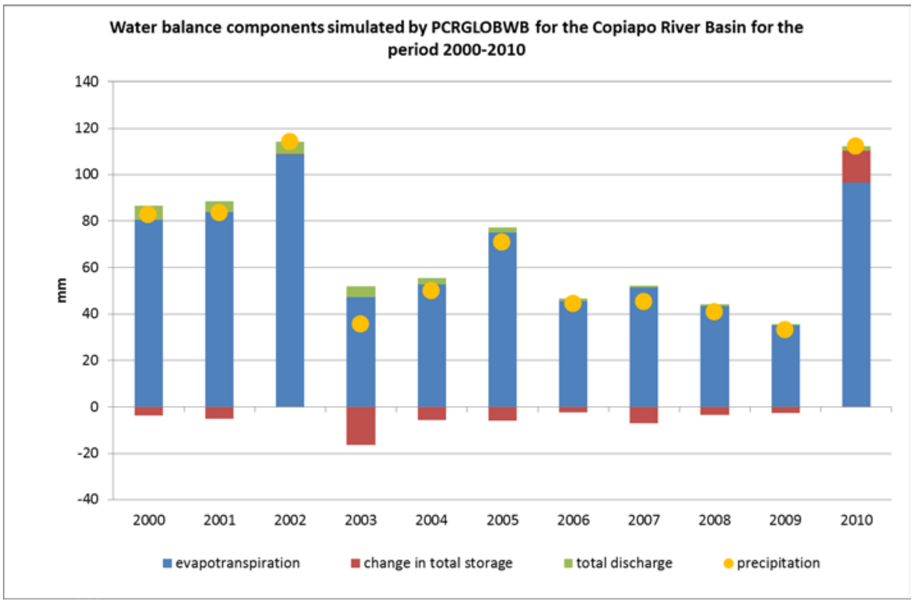

Figure 13. Annual total water balance components as simulated by the PCRGLOBWB model for the period 2000-2010.

In the years 2000, 2002, and 2010 more precipitation than evapotranspiration can be seen while for other years In 2003 a relatively large change in storage (-16 mm) is simulated. This response can be explained by the large evapotranspiration (109 mm) simulated in the year 2002. The average discharge simulated for the area is low (around 3 mm) and for several years almost no discharge is simulated at all (2007-2009). This corresponds to the actual situation, in which no surface runoff is observed in the basin (Figure 14), only during extreme rainfall events.

Figure 14 Inpression of landscape in Copiapó River basin. Picture: Enrique Playan (CSIC).

Lower Rio Grande River Basin, Mexico

The Mexico case study is not defined by a natural catchment area in the PCRGLOBWB model since the catchment area on the US side is omitted from our study area. Only the lower Rio Bravo Basin downstream of the Falcon Reservoir in the North East of Mexico is modelled (Figure 15 and Figure 16). For modeling purposes several adjustments had to be made to simulate water flows in the area. For example, an artificial local drain direction map was used with a single artificial outlet, since the area drains at the mouth of the Rio Grande and at many points into the lagoon. The inflow from the Falcon Reservoir into the Rio Grande was obtained from timeseries of IBWC (http://www.ibwc.state.gov/Water_Data/rtdata.htm). Also the diversion of flow from the Rio Grande into the Anzalduas Canal near Reynosa was modelled using timeseries from the IBWC (http://www.ibwc.gov/wad/DDQDANZC.htm).

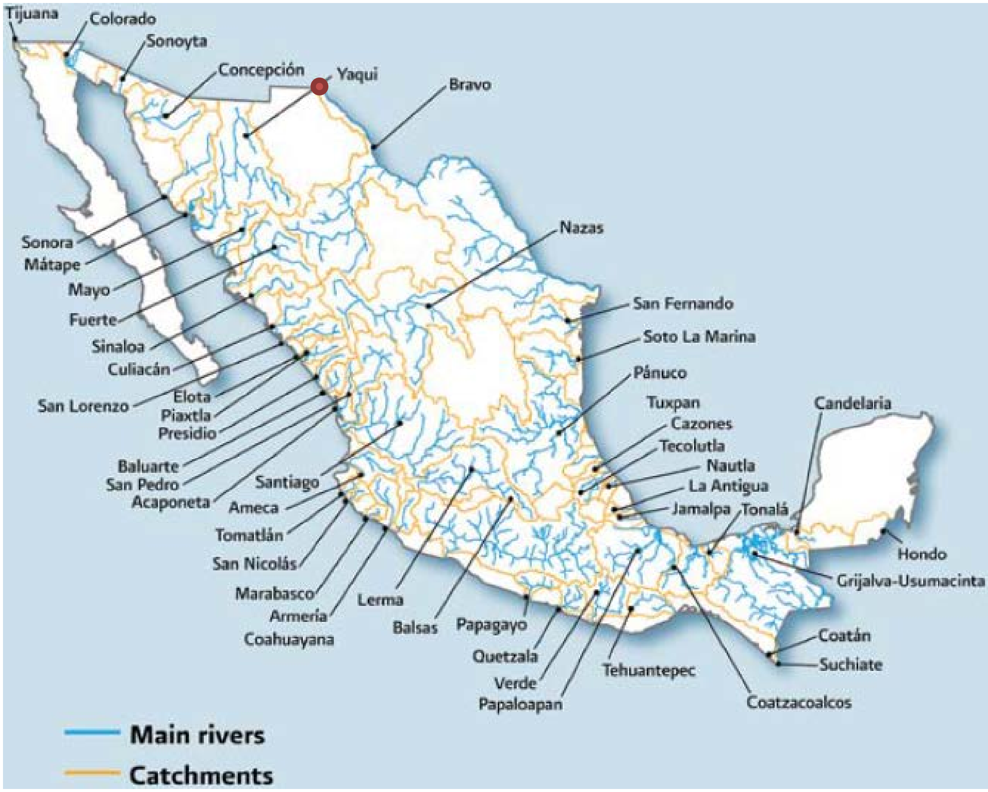

Figure 15. Main rivers with their catchment areas in Mexico. The red point in the North indicates the Falcon dam. Source: CONAGUA, 2010, Deputy Director General's Office for Technical Affairs.

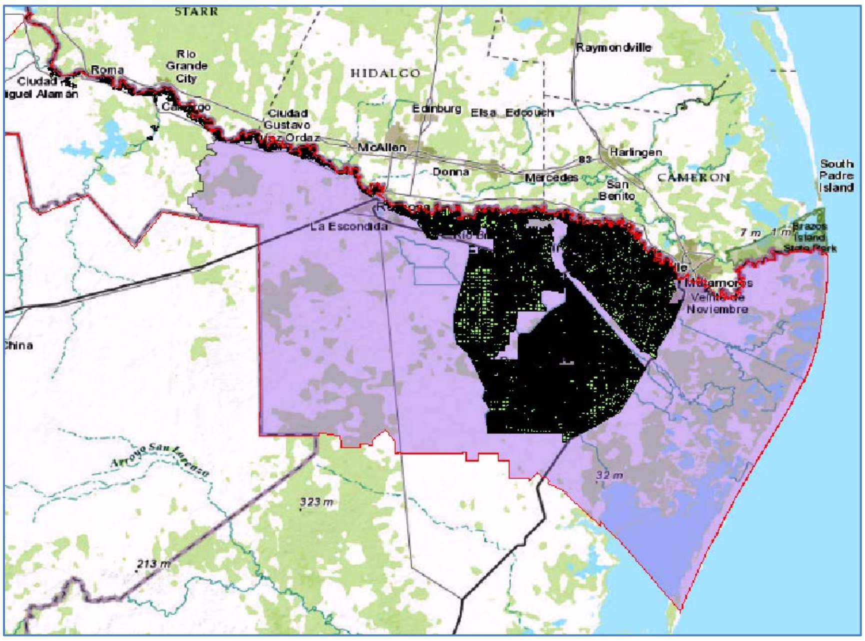

Figure 16. Study site boundary for the Mexican study site is shown in the purple area. The north boundary is the Rio Grande river. Note that this boundary does not represent a hydrological basin. The Falcon dam can be found on the top left corner of the image.

The results of the PCRGLOBWB simulations between 2000 and 2010 can be found in Figure 17. Besides the evapotranspiration, precipitation, change in total storage and total discharge such as for the other sites, also the inflow from the Falcon reservoir is given.

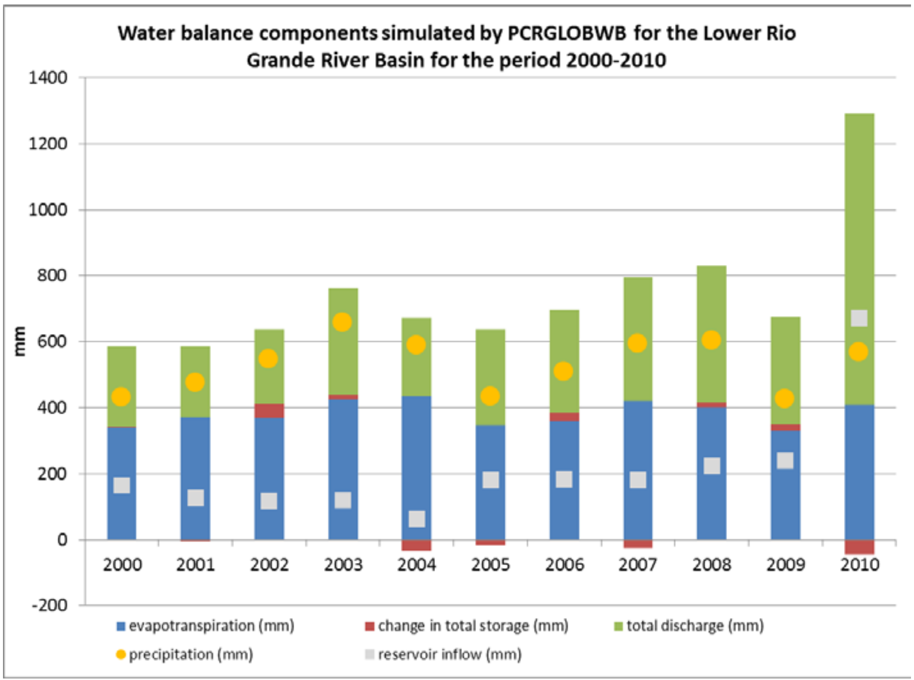

Figure 17. Annual water balance components for the Rio Grande river in Mexico.

A large inflow from water from the Falcon dam (881 mm) in 2010, is due to the high precipitation outside of the study area (Figure 18) during the arrival of hurricane Alex in the area (IWBC, 2010 and Eliud Ramirez, pers. comm.). The extra amount of water from the reservoir between July and August in that year was estimated at 1700 $m^3.s^{-1}$.

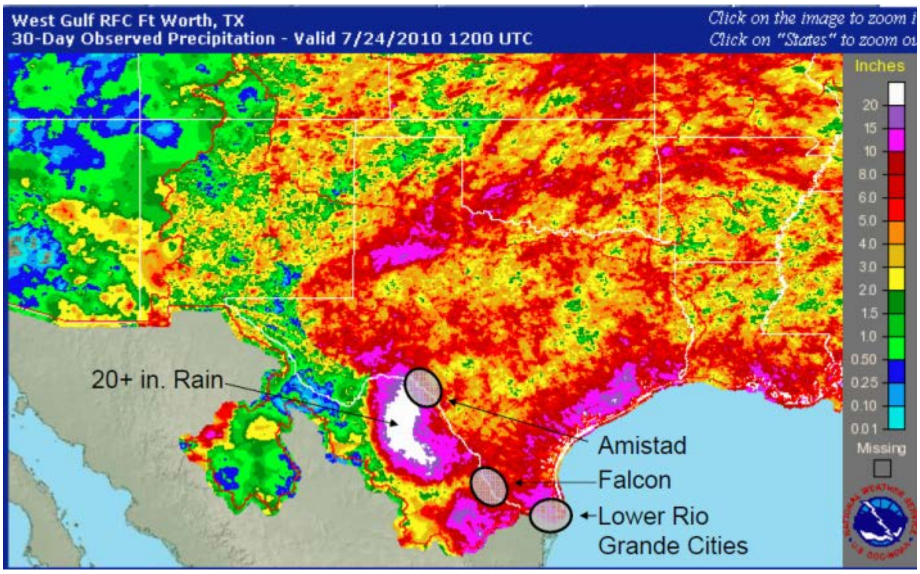

Figure 18. High precipitation (up to 20 inches or 51 cm) Taken from IBWC (2010).

One water supply point close to Reynosa city has been used to illustrate variations in the monthly discharge in the river basin (Figure 19). As can be seen the precipitation in the study area is not exceptionally high in the year 2010, though the discharge reaches a high value. On average the total discharge is around 70 $m^3.s^{-1}$ at this point.

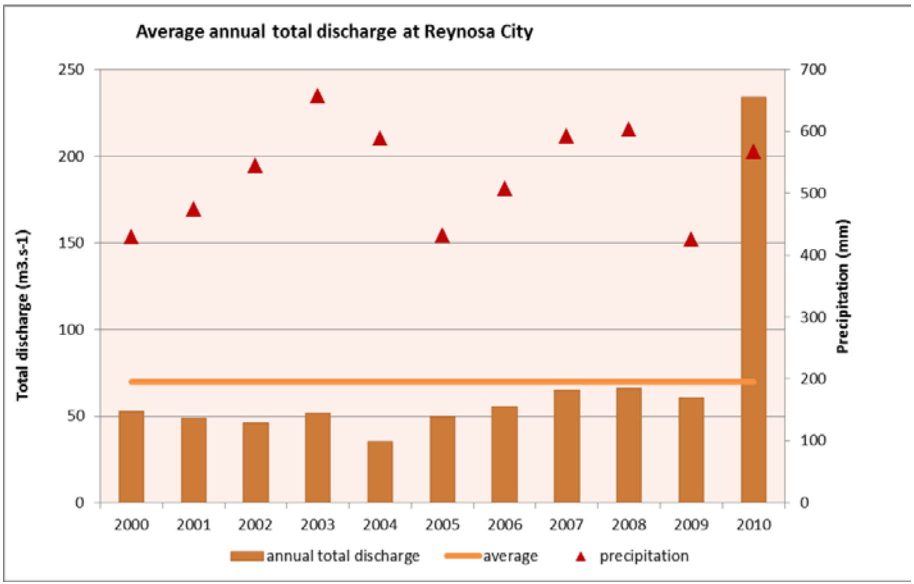

Figure 19. Annual discharge for the Reynosa City in the Rio Grande river. The orange horizontal line represents the average value for the period.

Simulated monthly mean discharge for the supply point close to Reynosa is shown in Figure 20. The discharge is variable throughout the year with a peak in July, which may be explained by the increased discharge caused by hurricane Alex as mentioned above. This can also be verified by the percentiles in that month which do not encompass the average line indicating that these high discharges are not common in this month. The total discharge drops to 36 mm if 2010 is omitted from the calculation. Lower discharges can be found in December and January.

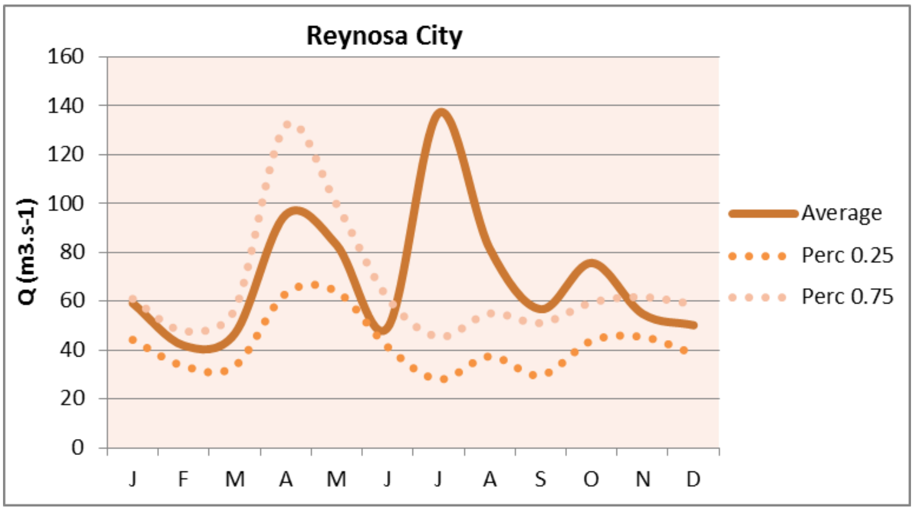

Figure 20. Mean monthly discharges for Reynosa City as simulated by the PCRGLOBWB model for the period 2000-2010. The solid line shows the average discharge, the dotted line the 25th percentile and the faded dotted line the 75th percentile.

2.4 Assessment of blue and green water availability under baseline conditions: regional domain

Figure 21 presents the potential blue water availability (mean monthly discharge) for Latin America according to the regional domain modelling results for the baseline situation (period 2000 – 2010). Due to the size of the simulated area and the wide range of the discharge (0 – 2.5E10^5 m^3.s^{-1}), discharge values were log-transformed to visually improve the variations. Darker colors represent low discharge and lighter colours high discharge. In Mexico the lowest discharges can be observed in the period May and June, the highest discharges seem to be around December. From August through November relatively low discharges may be noticed near the centre of South America. According to a statistical analysis of the modelling results, Latin America has on average the highest discharge in the period April - May and the lowest discharge in the period November – December.

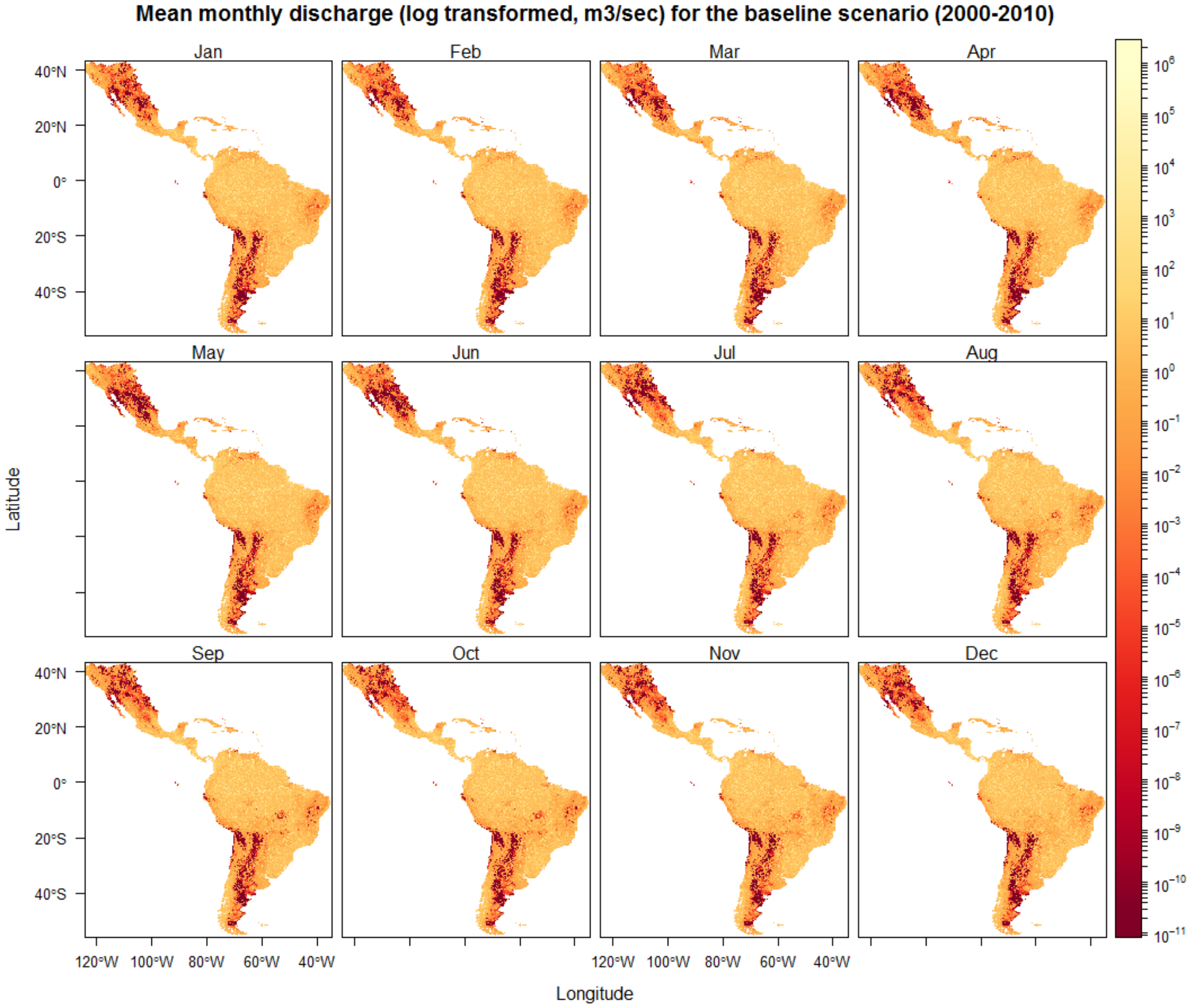

Figure 21. Maps with blue water availability (mean monthly discharge) per month for Latin America according to the regional domain modelling results for the baseline situation (period 2000 – 2010). Presented discharge values are log-transformed.

Figure 22 presents per month the mean monthly precipitation for Latin America according to the regional domain modelling results for the baseline situation (period 2000 – 2010). Darker colors represent low precipitation and lighter colors high precipitation. Now, the differences between the months are very clear. From January until August, South America seems to be receiving less and less precipitation, starting in the southern part and moving in the northern direction. From September until December the continent seems to be receiving more precipitation. A statistical analysis indicates that August is the driest month and March the wettest month.

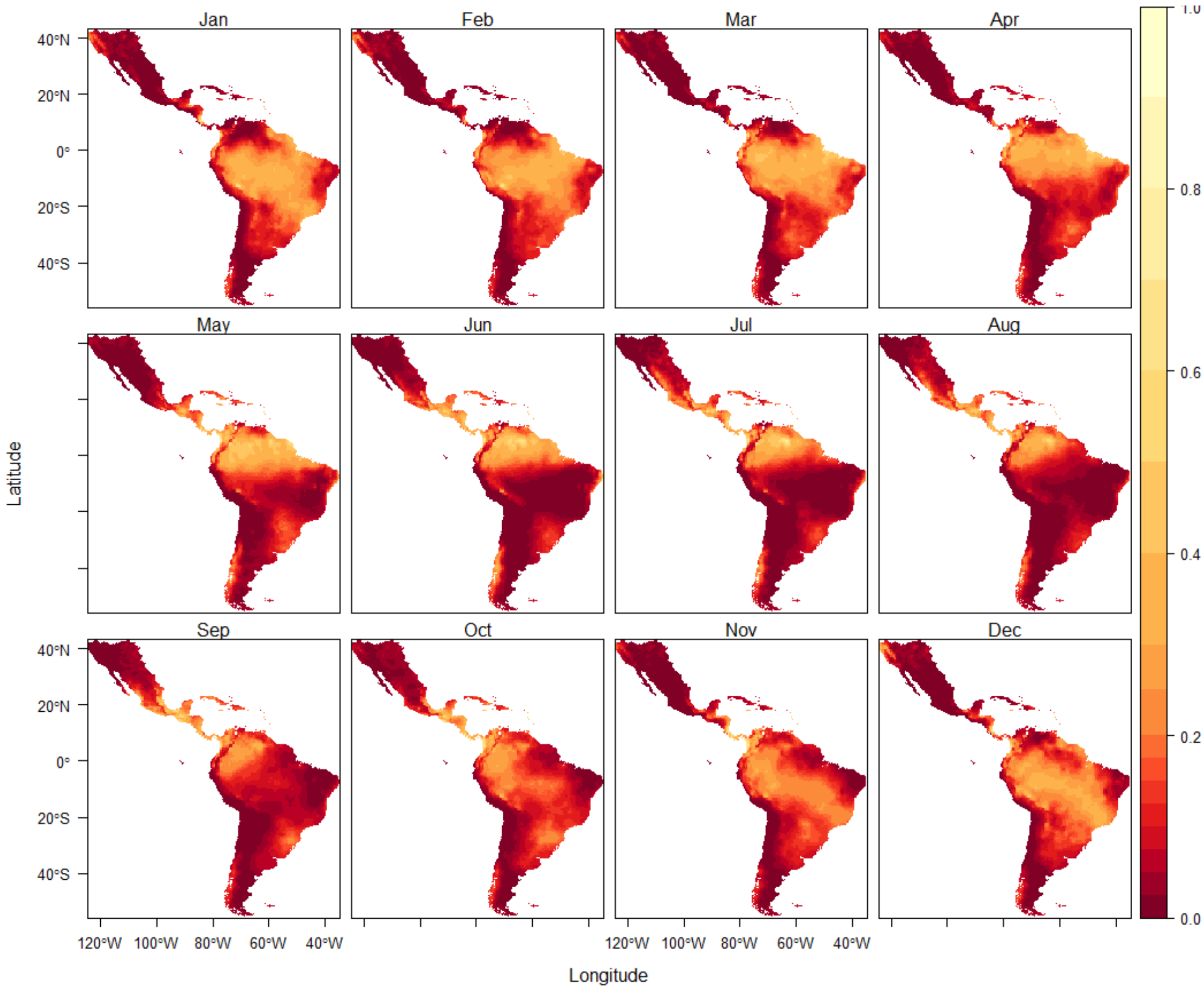

Figure 22. Maps with mean monthly precipitation per month for Latin America according to the regional domain modelling results for the baseline situation (period 2000 – 2010).

The mean monthly actual evapotranspiration for Latin America according to the regional domain modelling results for the baseline situation (period 2000 – 2010) is presented in Figure 23. The actual evapotranspiration can be interpreted as the green water flow, i.e. the rainfall that infiltrates in the upper unsaturated soil layer, and flows back to the atmosphere as vapor and evapotranspiration (Falkenmark & Rockström, 2010b). According to a statistical analysis the evapotranspiration is in general highest in the period December - January and lowest in June. However, this of course differs depending on the region of interest.

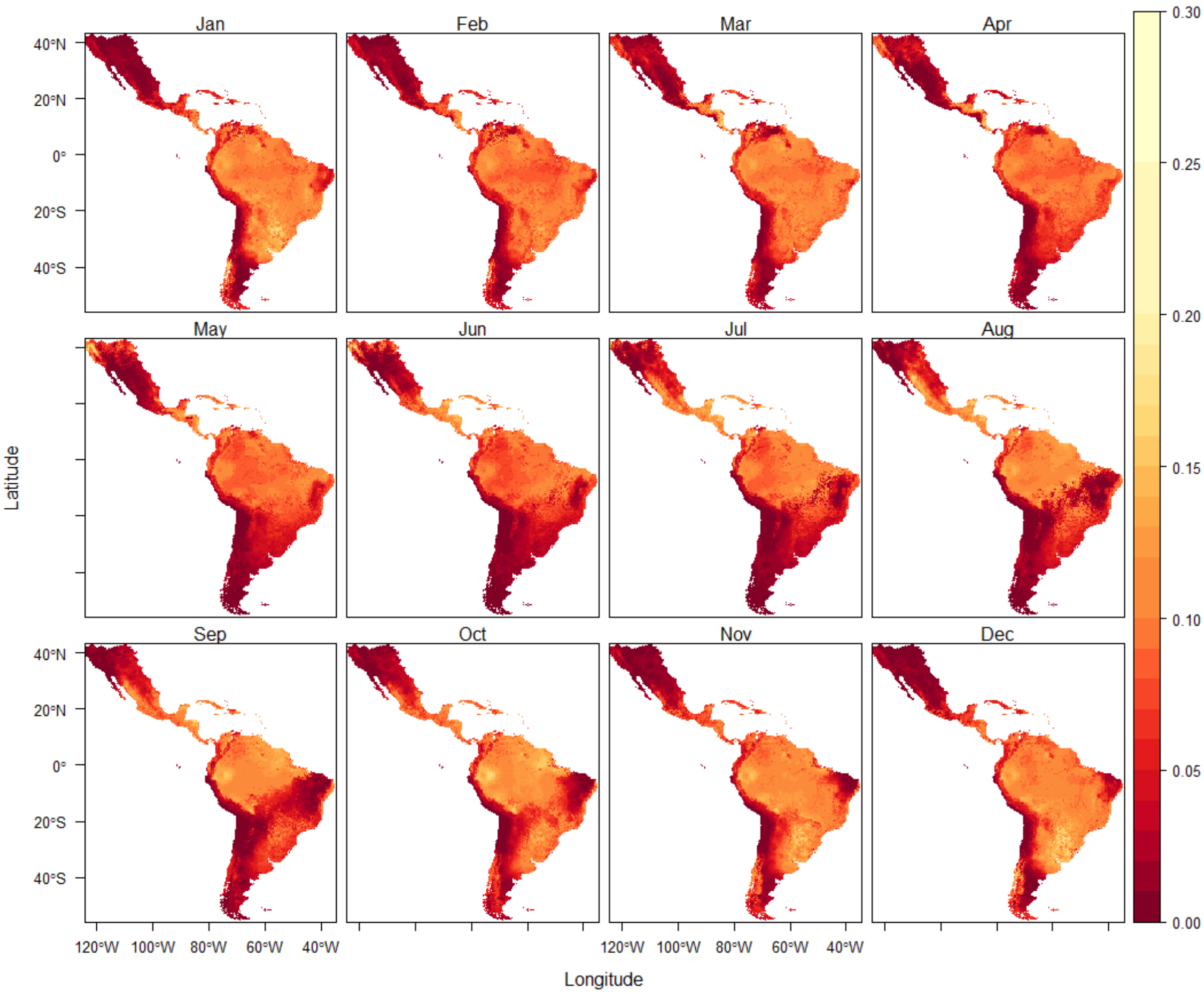

Figure 23. Maps with mean monthly actual evapotranspiration per month for Latin America according to the regional domain modelling results for the baseline situation (period 2000 – 2010).

2.5 Assessment of blue and green water availability under scenarios of climate change: local domain

2.5.1 Method

Climatic data from General Circulation Models (GCM) are often used as input for hydrologic models when hydrologic impacts of climate changes are investigated. A number of different GCMs exist, and they simulate different results. The future climate simulated by these models depends in part on greenhouse gas concentration trajectories (i.e. on 4 possible Representative Concentration Pathways (RCP)), and partly on the GCM choice. Mean monthly gridded climate data from 19 GCMs in connection with the four RCP scenarios (some GCMs have not include all RCPs in their simulations) and historical climate data (1950-2000) where downloaded from the WorldClim website (WorldClim, 2011). The GCMs used are from the most recent climatic projections used in the Fifth Assessment report.

In order to include the uncertainty in the different GCMs and RCPs, five different climatic scenarios were chosen among the available 63 different scenarios. These monthly data were then compiled to annual data. Following the procedure described in the website (Meted.ucar.edu, 2012) we plotted the 63 different scenarios as predicted percent change between the historical and future predicted average annual precipitation on the x-axis, and difference between historical and predicted future increase in temperature (all models produced increases in annual average mean temperature) on the y-axis. Five models where then chosen from the 63 model runs to model five scenarios for each of the catchments: ‘M’, ‘P90T90’, ‘P90T10’, ’P10T10’ and ’P10T90’. These five scenarios are described in Table 1. Figure 25 shows an example on how such a scatterplot and model selection is constructed. Each of the percentiles corresponds to the precipitation or temperature change that is associated with the given percentile from the corresponding cumulative distribution function.

Table 1. The five chosen scenarios with the corresponding temperature and precipitation changes.

Scenario	Precipitation change	Temperature change
M	Median	Median
P90T90	90th percentile	90th percentile
P90T10	90th percentile	10th percentile
P10T10	10th percentile	10th percentile
P10T90	10th percentile	90th percentile

The final model selections for the different local catchments are described in Table 2, where the two letters describe the GCM (http://www.worldclim.org/cmip5_30s) while the numbers describe the representative concentration pathway (RCP, http://en.wikipedia.org/wiki/Representative_Concentration_Pathways).

Table 2. The different climatic models which represent the 5 scenarios and 4 different local catchments

Model Scenario	Argentina	Brazil	Chile	Mexico
Median	cc60	he26	bc45	cc45
P90T90	gf85	hg85	cn85	ac85
P10T90	mp85	gf45	ip85	he85
P10T10	hd26	gd60	no45	mp26
P90T10	hg45	no26	bc26	cn26

The data used for creating projected future climate time series represents the period for the 2050s (2041-2060). These data are given in monthly averages (monthly average total precipitation and monthly average temperature) and are spatially downscaled and bias corrected by WorldClim (Hijmans et al. 2005; WorldClim 2011). In order to use these data as input to the hydrological model, the data needed to be processed into daily time series. This was done by first transforming the monthly data into multiplication and addition factors, which is done by dividing or subtracting the projected future climate data with the historical climate data (1950-2000). This technique is often referred to as the delta method and retains the fundamental temporal and spatial variability of the observed climate but adjusts the observed daily climate records in each month by the projected changes in the monthly mean precipitation and temperature from the GCM scenarios.

- Precipitation multiplication factor = future projected precipitation/current precipitation
- Temperature addition factor = future projected temperature – current temperature
- Reference evapotranspiration multiplication factor = future projected evapotranspiration/current evapotranspiration

Reference evapotranspiration needed as input for the PCRGLOBWB model, which is not a part of the WorldClim data (current or future), was constructed with the modified Hargreaves equation (Sperna Weiland, Tisseuil, Dürr, Vrac, & van Beek, 2012) shown in equation 1.:

1. $ET_0 = 0.0031 * R_a * (\bar{T} + 17.8) * TR^{0.50}$

Where R_a = extra-terrestrial radiation (mm), $\bar{T}$ = mean temperature (˚C), TR = temperature range (˚C).

These monthly conversion factors were applied to the "baseline" daily climatic time series in order to construct future climatic daily time series as input to the PCRGLOWB model. The downscaling of climate input data from monthly to daily timeseries was automated in a script created using the PCRaster Package (http://pcraster.geo.uu.nl/pcraster/4.0.0/doc/manual/secintro.html). PCRaster is a Geographical Information System which consists of a set of computer tools for storing, manipulating, analyzing and retrieving geographic information. The script is available as part of the WP4-tool.

2.5.2 Assessment of water availability at the local scale under scenarios of climate change

This chapter shows the scenarios for potential water availability at the local scale for the different study sites. The catchment-average changes in precipitation and temperature according to the five selected scenarios for the case study sites are listed in Figure 24. The figure shows that increases in precipitation of 12-13% are expected for the case study sites in Brazil and Argentina under the 'wetter' (P90) scenarios. For the area in Chile also an increase is expected, but because the absolute value of the annual catchment-averaged precipitation is so low in this area (30-120 mm according to the climate input data used in this study, see Annex 1.1), the change is also small. For the area in Argentina, an increase in precipitation is expected under all scenarios, and therefore the naming 'drier' for the P10 scenarios is not appropriate for this area. A decrease in precipitation is projected for the case study sites in Brazil, Chile and Mexico under the 'drier' scenarios (P10), by 20-25% is projected for the case study site in Chile, and between 7 and 12% for Brazil and Mexico. Projected increases in temperature in the case study sites are between 0.8 and 1.3 °C in the 'warmer' scenarios (T10), and between 1.9 and 3.0 °C in the 'hotter' scenarios (T90).

Brazil			
Climatic model	Scenario	% change precipitation	Change in temperature (˚C)
he26	Median	4.8	1.6
hg85	Hotter and wetter	12.0	2.4
gf45	Hotter and drier	-7.7	2.6
gd60	Warmer and drier	-7.7	1.2
no26	Warmer and wetter	12.6	0.8
Argentina			
Climatic model	Scenario	% change precipitation	Change in temperature (˚C)
cc60	Median	6.1	1.9
gf85	Hotter and wetter	12.1	2.6
mp85	Hotter and drier	2.5	2.5
hd26	Warmer and drier	0.8	1.3
hg45	Warmer and wetter	13.6	1.2

Chile			
Climatic model	Scenario	% change precipitation	Change in temperature (˚C)
bc45	Median	-8.1	1.3
cn85	Hotter and wetter	5.9	1.9
ip85	Hotter and drier	-20.3	2.2
no45	Warmer and drier	-24.1	0.9
bc26	Warmer and wetter	12.9	0.8

Mexico			
Climatic model	Scenario	% change precipitation	Change in temperature (˚C)
cc45	Median	-2.8	1.9
ac85	Hotter and wetter	8.7	2.7
he85	Hotter and drier	-11.8	3.0
mp26	Warmer and drier	-8.4	1.3
cn26	Warmer and wetter	6.8	1.3

Figure 24 Projected changes in precipitation and temperature in the case study sites for the period around 2050, compared to the historical climate over the period 1950-2000. Hotter and wetter: P90T90 scenario; Hotter and drier: P10T90 scenario; Warmer and drier: P10T10 scenario; Warmer and Wetter: P90T10 scenario.

The climate change scenarios and resulting projections of available water are discussed in detail in the paragraphs below.

2.5.2.1 Future climatic scenarios Brazil

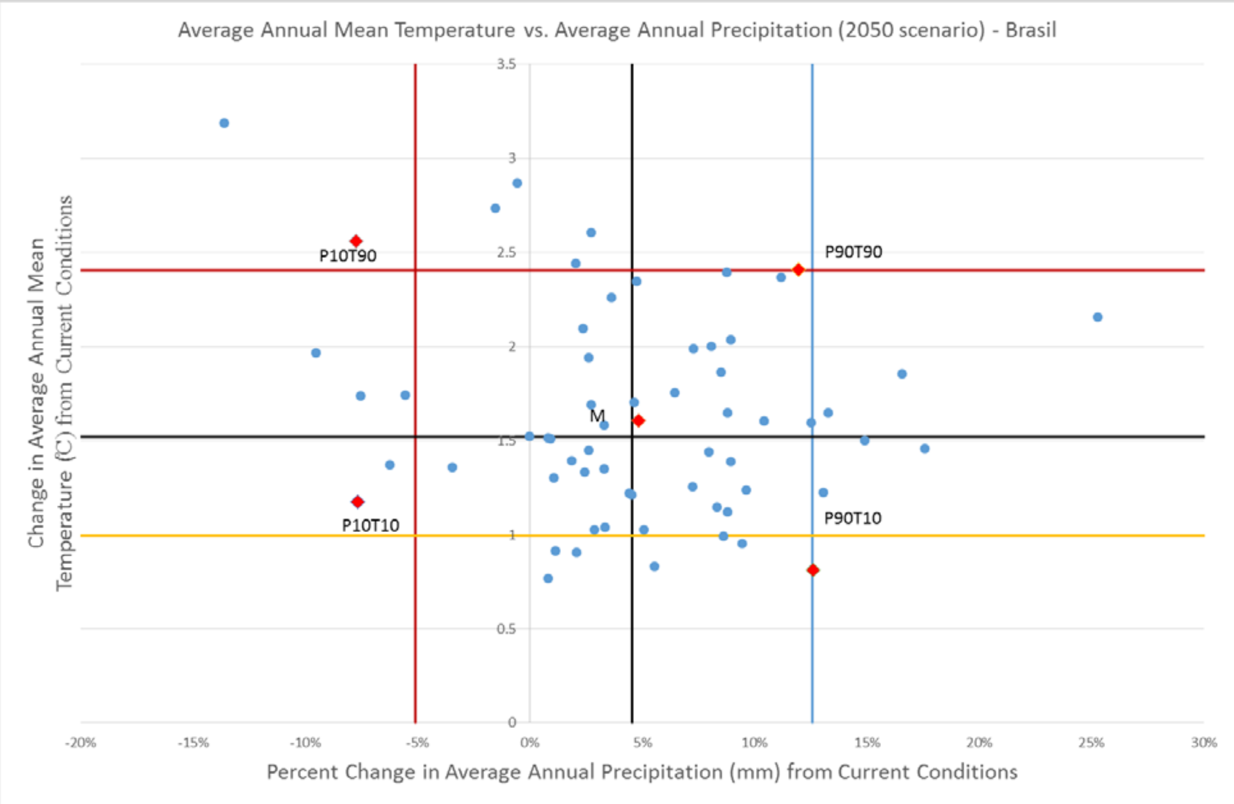

Figure 25. Five future climatic models as selected from 63 models for Upper Tiête River Basin, Brazil.

For the Upper Tiête River Basin in Brazil, a majority of the General Circulation Models (GCMs) and scenarios project an increase in precipitation on a mean annual scale for the 2050's, as can be seen in Figure 25 (most projections have a positive value on the x-axis). The five selected scenarios are shown as red diamonds. All the GCMs and RCPs project an increase in temperature compared with the historical temperature (change in average annual mean temperature is above 0% for all scenarios).

Figure 26 shows the historical mean monthly precipitation and temperature for the upper Tiete River basin in Brazil from the 1950-2000 period. This figure has been constructed by calculating mean temperature and precipitation from the downloaded WorldClim climatic raster maps for the historical period, i.e. these are average data for the whole catchments and not from a point measurements. Precipitation is lowest in the months March to September and highest between October and February. Other modelled monthly precipitation and temperature of the scenarios can be found in annex 1.4.

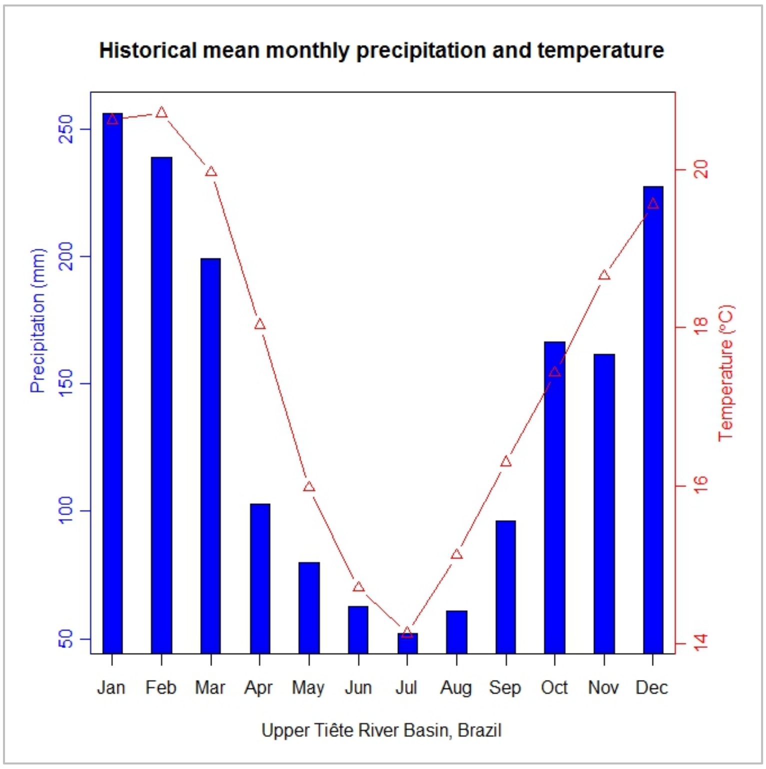

Figure 26. Historical (1950-2000) mean monthly precipitation and temperature for the upper Tiete River basin in Brazil.

The land use map used for the different scenarios is presented in Figure 27. No land use change is assumed in the projected future scenarios. The main surfaces in the upper Tiete river basin include urban or urbanized areas, and forest.

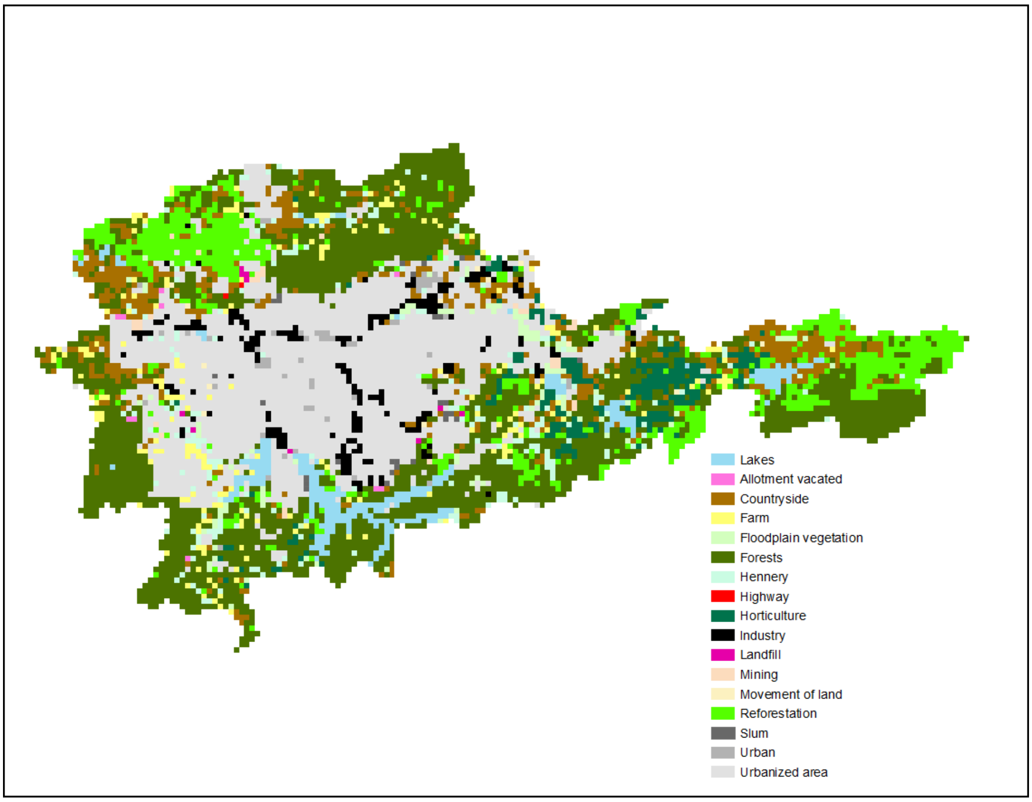

Figure 27. Land use in Upper Tiête River Basin, Brazil

In Figure 28 the summary of comparison between baseline mean discharge and P10T90 scenario mean discharge is shown. The difference is calculated on a cell to cell basis where the future projected scenario is divided with the baseline scenario. Values below 1 represent a decrease in water availability (red colours); values higher than 1 represent an increase in water availability (blue colours), while values around 1 represent no or little change (white).

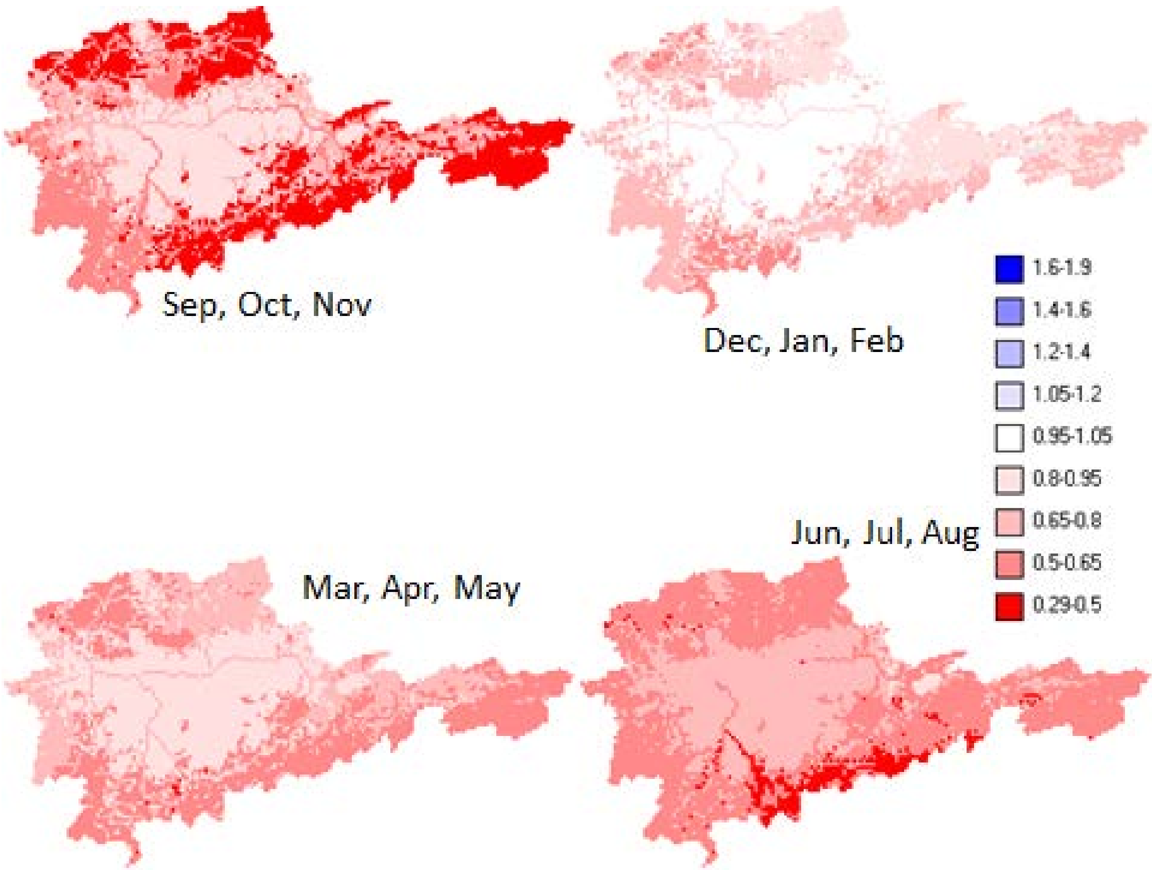

Figure 28. Ratio of P10T90 scenario discharge to baseline discharge (B/A) for all the seasons.

For the P10T90 scenario potential water availability decreases everywhere in the catchment September-November period; mostly in the forested areas on the borders that are feeding the catchment, and least in the city. A decrease in water availability in the forested boarders of the city is disadvantageous for the supply of surface and groundwater to the city and so for domestic and industrial use (industries pump up groundwater in the city). Relative average decrease of potential water availability is 37.4% for the whole catchment in the September-November period.

In the December-February period almost no change in potential water availability is simulated in the city together with a slight decrease in potential water availability along the borders. The southern part of the catchment feeding the drinking water reservoirs of Guarapiranga and Billings has reductions in potential water availability of 35-50%. Average relative decrease of potential water availability is 14.1% for the whole catchment in the December-February period and P10T90 scenario.

A decrease of potential water availability is simulated across the whole basin for the March-May period. The largest differences can be found in the forested areas while the least changes are found in the urbanized areas. For the P10T90 scenario, the projections of future water availability show a decrease in the whole basin for all the seasons, except for the December-February season where potential water availability only decreases outside the urban areas. Areas feeding the drinking water reservoirs (southern border) have relatively high reductions in water availability in the September-November period (20-30%) and the June-August period (50-70%).

Figure 29 shows the summary of comparison between baseline mean discharge and P90T10 scenario mean discharge.

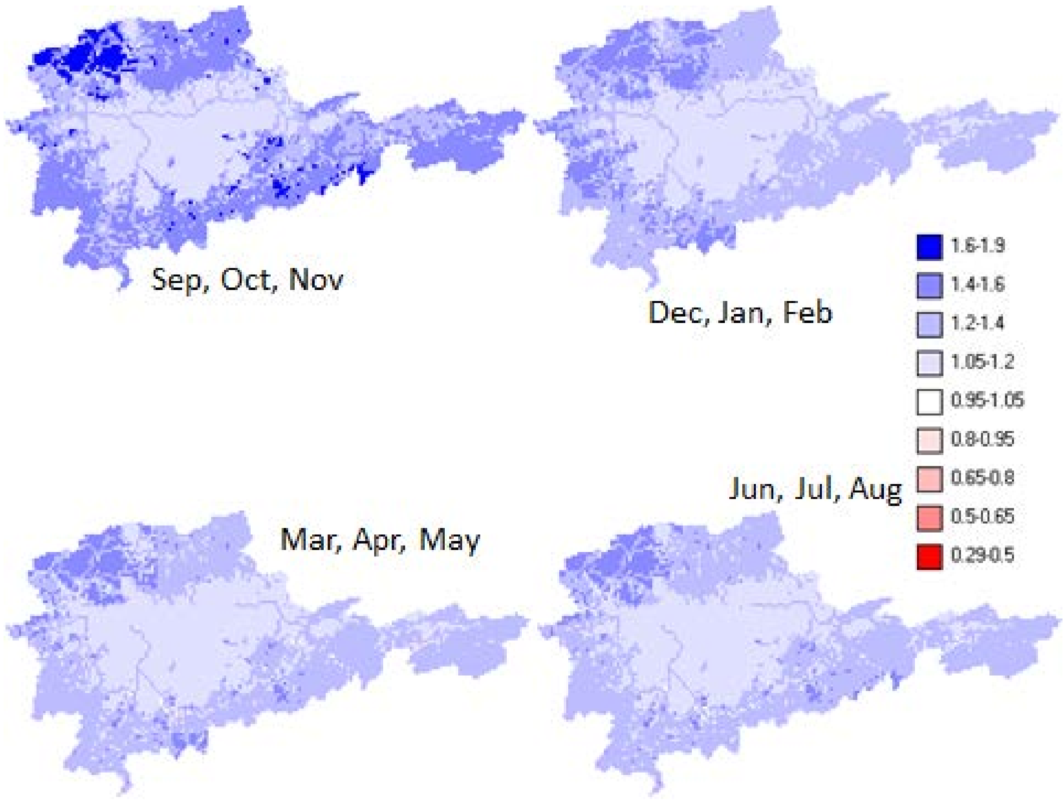

Figure 29. Ratio of P90T10 scenario discharge to baseline discharge (B/A) for all seasons

For the P90T10 scenario, potential water availability increases in the whole catchment, especially in September-November period (with up to 60-90%). Largest increase in potential water availability is projected for the forested areas in the north-western part of the catchment; the smallest (5-20%) in the urbanized areas.

Table 3 shows the mean of the ratios for all 5 future scenarios that have been simulated. In general, with the scenarios that project an increase in precipitation (i.e. 90th percentile precipitation) compared to the historical climate, the hydrological simulations produce an increase in potential water availability. The median scenario simulates almost no change in potential water availability (a small decrease is simulated); while a decrease in potential water availability is simulated for the scenarios that project a decrease in precipitation.

Table 3. Means of the ratios for the 5 future scenarios

B/A average	P10T90	P90T90	M	P10T10	P90T10	mean
Sep, Oct, Nov	0.626	1.143	0.98	0.841	1.347	0.987
Dec, Jan, Feb	0.859	1.056	0.973	0.843	1.275	1.001
Mar, Apr, May	0.729	1.134	0.995	1.149	1.248	1.051
Jun, Jul, Aug	0.635	1.103	0.993	0.847	1.253	0.966
mean	0.712	1.109	0.985	0.920	1.281	

2.5.2.2 Future climatic scenarios Argentina

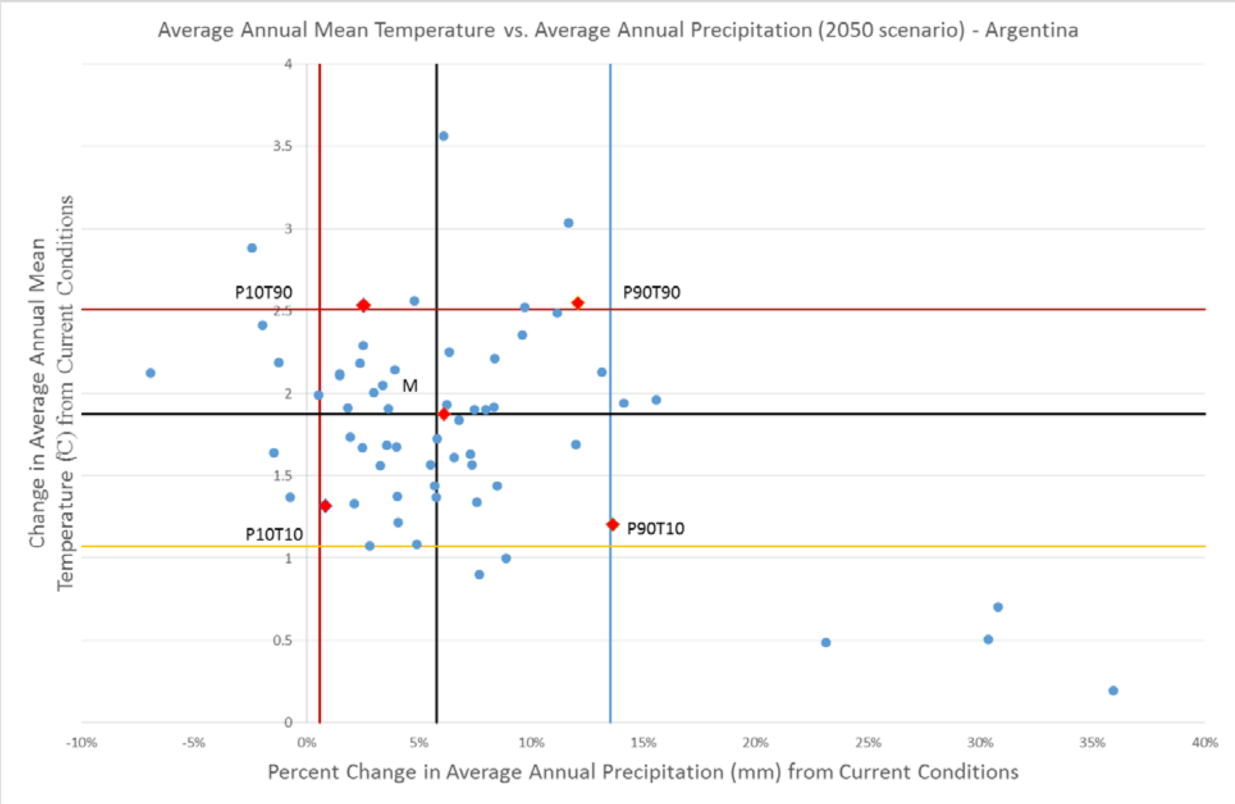

Figure 30. The five future climatic models which were selected from 63 models for Suquía River Basin, Argentina.

In general, for the change in mean annual precipitation, almost all of the 63 future scenarios project an increase in mean annual precipitation. All the GCMs with associated RCPs project an increase in temperature in the 2050's compared with current temperature. Red diamonds represents the GCMs selected as input for hydrological modeling.

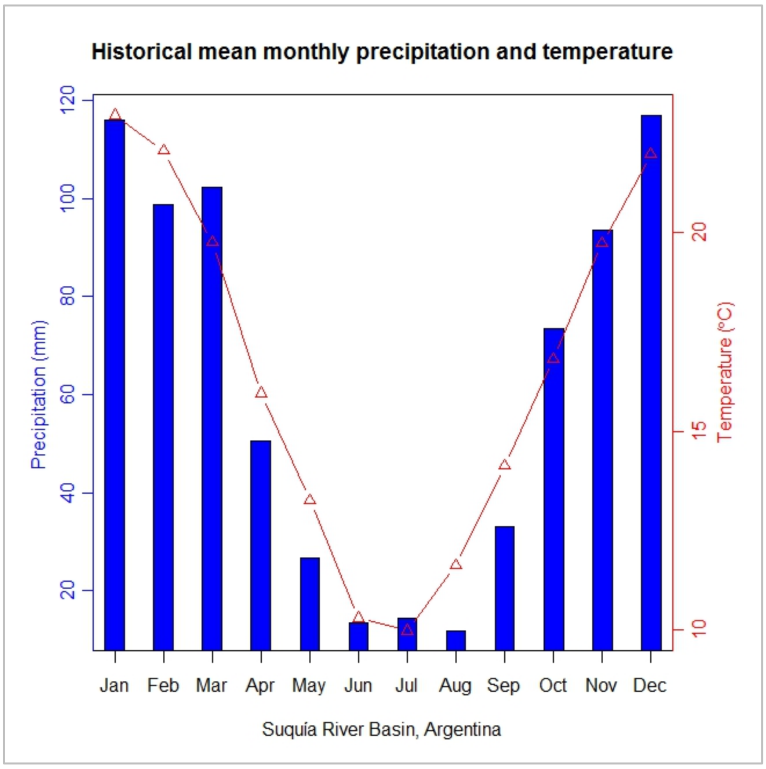

Figure 31. Historical (1950-2000) mean monthly precipitation and temperature for the Suquía River Basin, Argentina.

Figure 31 shows the historical (1950-2000) mean monthly precipitation and temperature for Suquía River Basin in Argentina. This figure has been constructed by calculating mean temperature and precipitation from the downloaded WorldClim climatic raster maps for the historical period, i.e. these are average data for the whole catchments and not from a point measurements.
Precipitation is lowest in the months May to September and highest between October and April. The temperature is low in May to September while in the rest of the period average monthly temperatures can reach above 20 degrees C. Future projected monthly precipitation and temperature of the scenarios can be found in annex 1.4.

The land use map of the Suquía River Basin is shown in Figure 32. Most of the land use in the area consists of mixed land use. The west side of the river basin consist of a mountainous area with forest, production forest and rocky outcrop. In this area higher precipitation is observed and is discharged through the catchment and has its discharge point in Mar Chiquita in the North East.

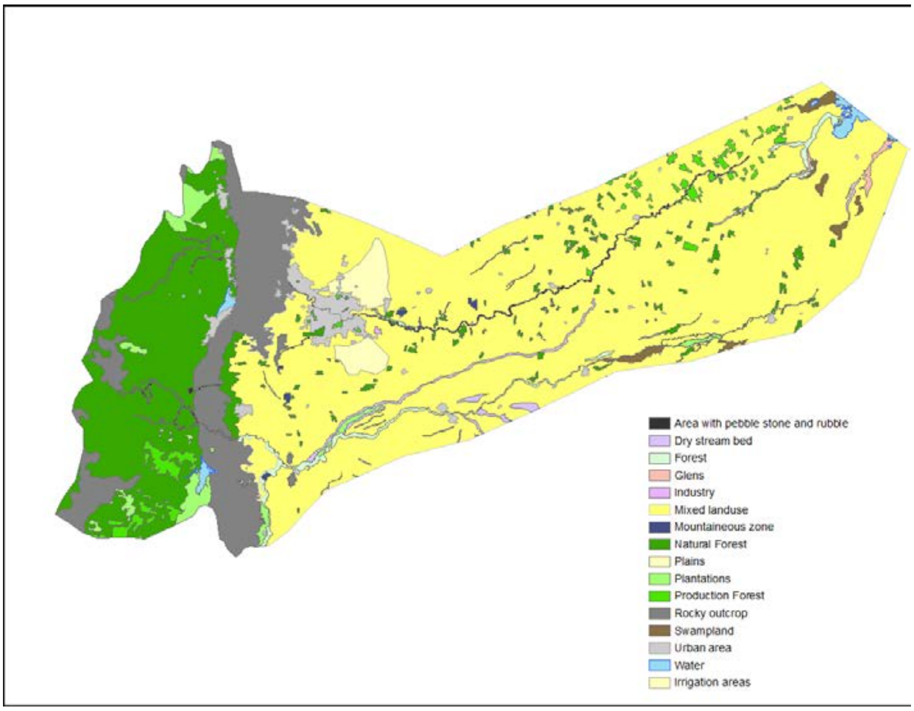

Figure 32. Land use map for Suquía River Basin, Argentina

In Figure 33 the summary of comparison between baseline mean discharge and P10T90 scenario mean discharge is shown. The difference is calculated on a cell to cell basis where the future projected scenario is divided with the baseline scenario. Values below 1 represent a decrease in water availability (red colours); values higher than 1 represent an increase in water availability (blue colours), while values around 1 represent no or little change (white).

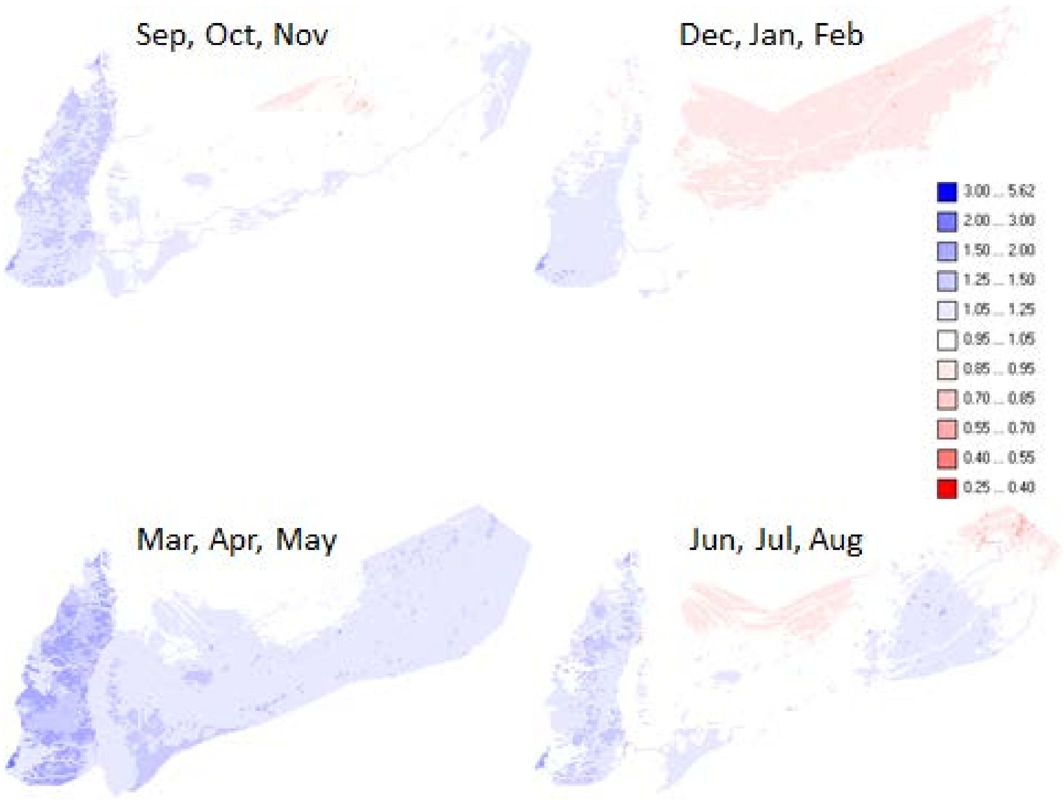

Figure 33. Ratio of P10T90 scenario discharge to baseline discharge (B/A) for all the seasons

An increase of potential water availability is simulated in the western part of the catchment and in the Los Molinos river (the southernmost river) for all the seasons; even in the driest future scenario there will be a slight increase in potential water availability here. The western part of the catchment (the mountainous part of the area) is very important for feeding the Suquia River. It is the 'water castle' for the lower part of the basin.

For the December-February season, the northern and central of the catchment (areas with red colours) experiences a decrease in potential water availability. This area is used for soybean production; an important export product for the Province. However, an increase in potential water availability is simulated in the mountainous western parts of the catchment.
In March-May period, higher potential water availability in the whole catchment is simulated with the PCRGLOBWB hydrological model. Again the highest increase of potential water availability is simulated in the mountains in the west. In the June-August period a similar process as in the December-February period is simulated with a difference that not the whole lower part of the catchment will experience decreased water availability. The southern part of the lower catchment has an increase in water availability.

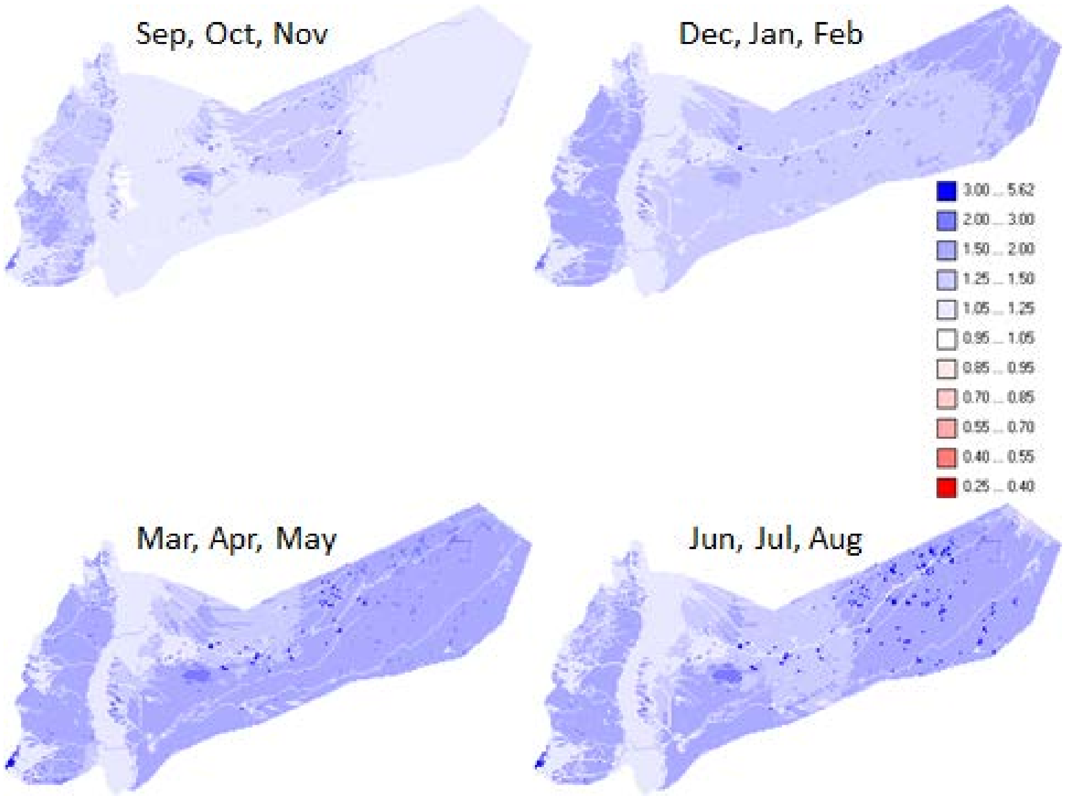

Figure 34. Ratio of P90T10 scenario discharge to baseline discharge (B/A) for the all the seasons.

In Figure 34 the summary of comparison between baseline mean discharge and P90T10 scenario mean discharge is shown.The irrigated zones north and south of Cordoba stand out as darker blue areas. The potential available water in the soil and groundwater increases here. This would reduce the requirement for irrigation water. This applies to all seasons, but least for the December-February period when irrigation requirement is highest.
Scattered cells with the darkest blue colour represent areas with production forest. Here water availability increases relatively more than in the surrounding lower part of the catchment. Like in the case of the irrigated areas, this could be related to the higher crop coefficient for this type of land cover. An explanation could be that the increase in ET generated by the warmer-wetter scenario is less here; due to the high kc ET was already high in the baseline situation. i.e. has reached its limit. This would leave more water in the soil and groundwater stores in these land covers.

In Table 4 average statistics for the whole Suquía River Basin is presented. Almost all of the future projected scenarios simulate an increase in water availability on a basin scale. The exception is the P10T10 scenario and the December-February season in the P10T90 scenario which both simulate a small decrease in water availability. It is a bit illogical that the P10T10 scenario simulates a larger decrease in water availability than the P10T90 scenario; in the P10T90 scenario the increase in potential evapotranspiration is large which should lead to a larger decrease in water availability. However, for the P10T10 model selection the increase in precipitation is smaller (0.8% increase) than for the P10T90 scenario (2.5% increase), which might explain why the P10T10 scenario simulates a lager decrease in water availability than the P10T90 scenario. For this catchment we do not observe a great reduction in water availability under any of the 5 climate scenarios, as we did for Brazil. Reductions are at most 13% in the P10T10 scenario, and then in the winter, which will not be harmful to the agricultural sector, but possibly for the urban/domestic sector. However, in most simulations and seasons, and in the most areas of the catchment, changes are slightly positive to positive (up to +50%), indicating that potentially available blue water will not be reduced under climate change in this area.

Table 4. Average basin values of the ratios of future scenario discharge to baseline discharge (B/A) for the 5 future scenarios

B/A average	P10T90	P90T90	M	P10T10	P90T10	mean
Sep, Oct, Nov	1.056	1.303	1.046	0.924	1.231	1.112
Dec, Jan, Feb	0.984	1.513	1.158	0.982	1.422	1.212
Mar, Apr, May	1.181	1.416	1.12	0.918	1.575	1.242
Jun, Jul, Aug	1.04	1.276	1.095	0.874	1.551	1.167
mean	1.065	1.377	1.105	0.925	1.445	

2.5.2.3 Future climatic scenarios Chile

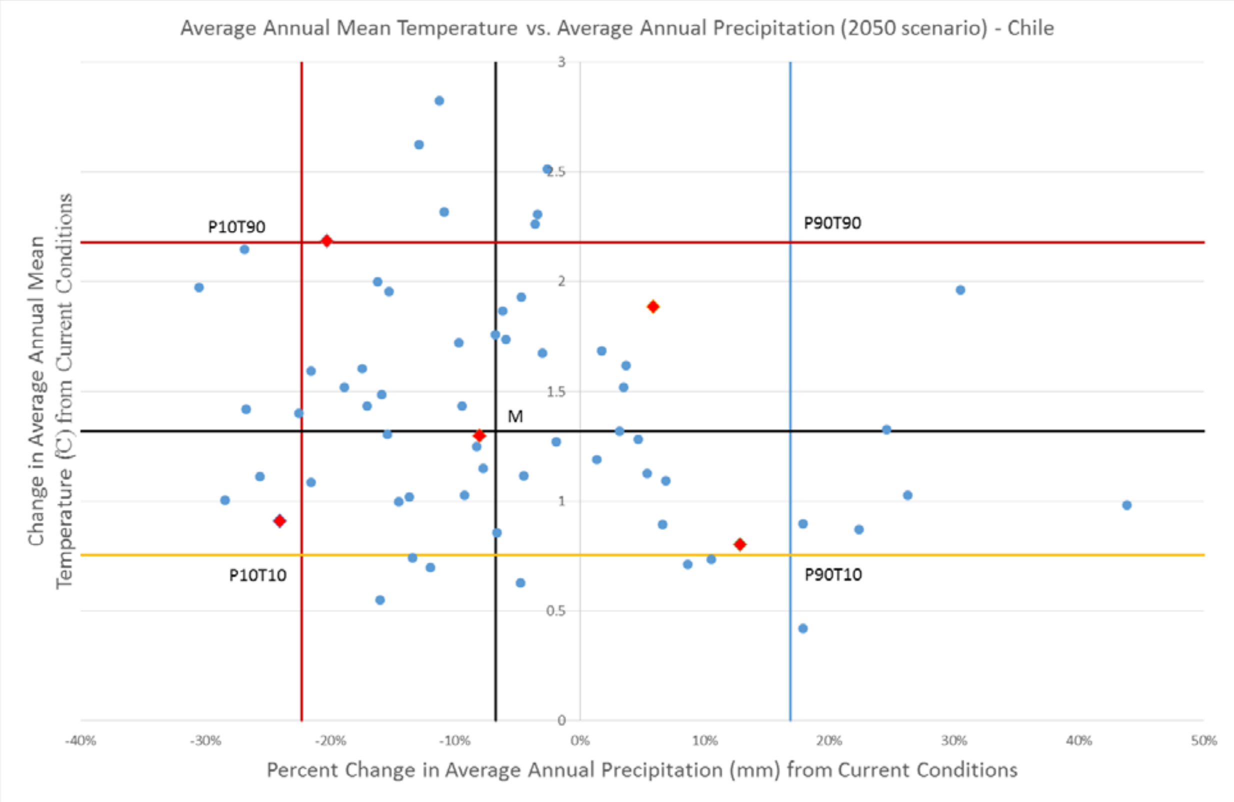

Figure 35. Five future climatic models were selected from 63 climatic models for Copiapó River Basin, Chile

A majority of the 63 GCM and RCP predictions simulate a drier environment in the Copiapó river basin compared to the historical period. All of the GCM and RCP predictions simulate an increase in temperature on an average annual scale for the 2050's. The five GCMs chosen are represented as red diamonds in Figure 35. Five future climatic models were selected from 63 climatic models for Copiapó River Basin, Chile

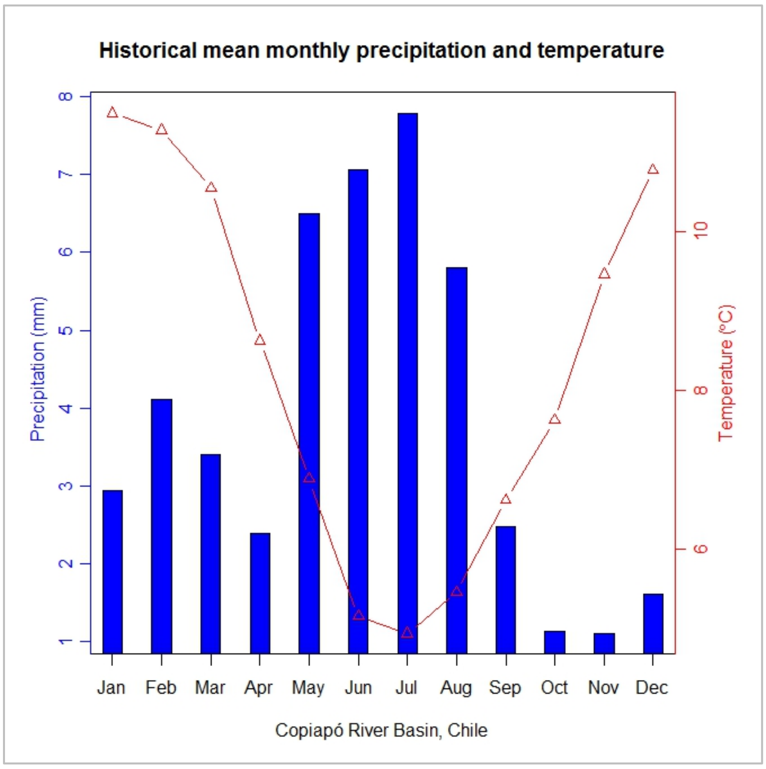

Figure 36. Historical (1950-2000) mean monthly precipitation and temperature for the Copiapó river basin, Chile.

Figure 36 shows the historical mean monthly precipitation and temperature for the Copiapó river basin. This figure has been constructed by calculating mean temperature and precipitation from the downloaded WorldClim climatic raster maps for the historical period, i.e. these are average data for the whole catchments and not from a point measurements. Generally, most of the precipitation that falls over the Copiapó river basin falls over the mountains in the east of the catchments. Here you find mountain ranges of up to 6000 m.o.s.l. Little precipitation falls over the low lying areas in the west close to the sea. Most of the precipitation falls between May and August and the coldest mean monthly temperatures are observed at this time period as well.

Land use in the region is shown in Figure 37. Around the Copiapo river irrigated agricultural is common. Mining takes place in the area as well, especially south of Copiapo city. The region is known for being desert-like and this can be seen in the legend as “other”.

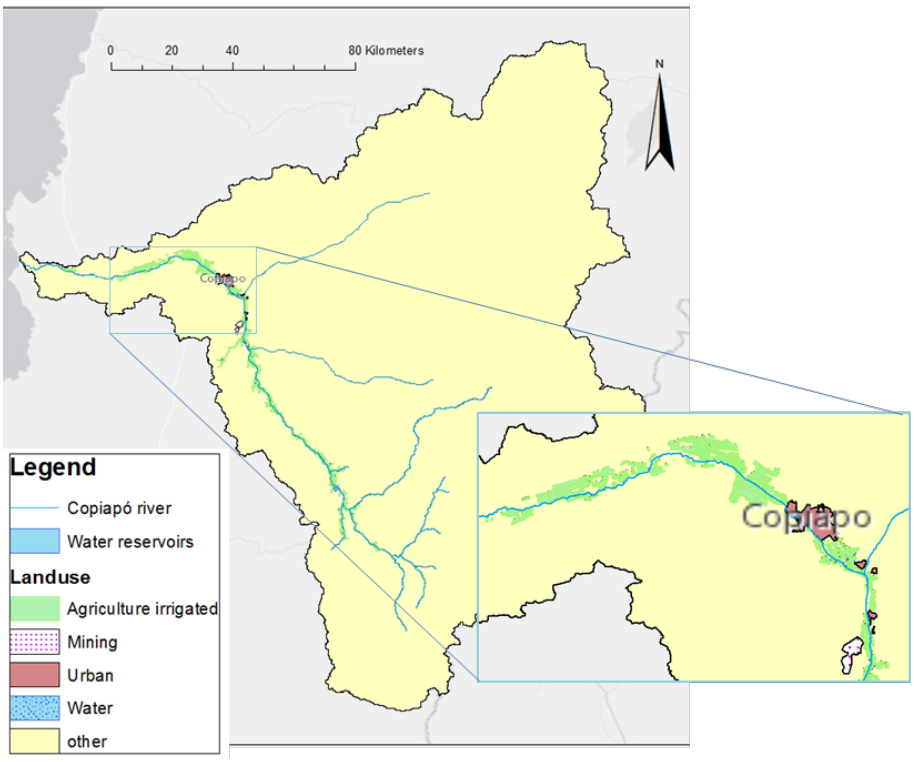

Figure 37. Land use in the Copiapó river basin.

Due to the relatively small values produced in some cells of the B/A map comparisons for the Copiapó river basin, the b/a technique is not a very good method to compare scenario to the baseline. For example, in a grid cell we find a value of 3.25*10^-5 for P90T10 scenario and a value of 1.68*10^-19 for the baseline. Dividing the scenario with the baseline produces a very big number which might be misleading, since we are dividing almost zero discharge with almost zero discharge; i.e. even though we simulate a relative increase in water availability of several thousands of percent, the absolute increase is close to zero and cannot be utilized for water use. Because of this we decided to compare the baseline with future projected discharge by the b-a method instead. With this method the mean future projected scenario is subtracted with the mean baseline scenario, producing an average absolute difference between the future and the current situation. Also, since most of the area consists of desert areas with no or very little water availability, we decided to only subset results from areas where currently water is being abstracted. Figure 33 shows the locations of the areas where water currently is being abstracted. These areas are situated along parts of the river network.

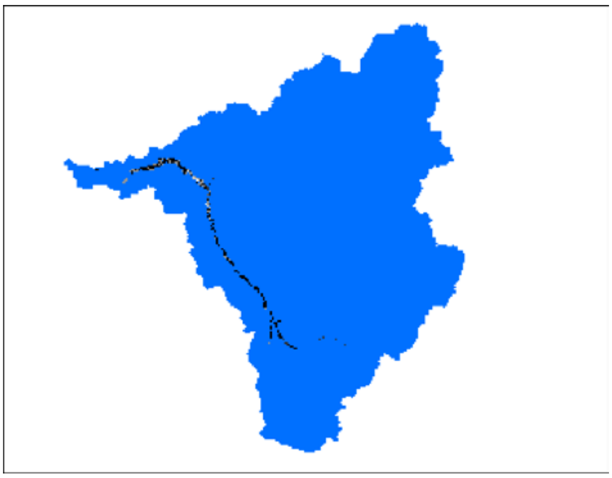

Figure 38. Map of water abstraction points (black, grey and white points) in the Copiapó river basin.

Presenting a result map showing only the areas of water abstraction gave little meaning because of the difficulty in discerning the colours and trends.

Because of this we decided to present the differences as histogram and as a combined box-whisker/violin plot as monthly averages (averaged over 11 years period for each scenario) as shown in e.g. Figure 39 and Figure 40. The differences refer to the 240 pixels where currently water is extracted either from the groundwater or the surface water.

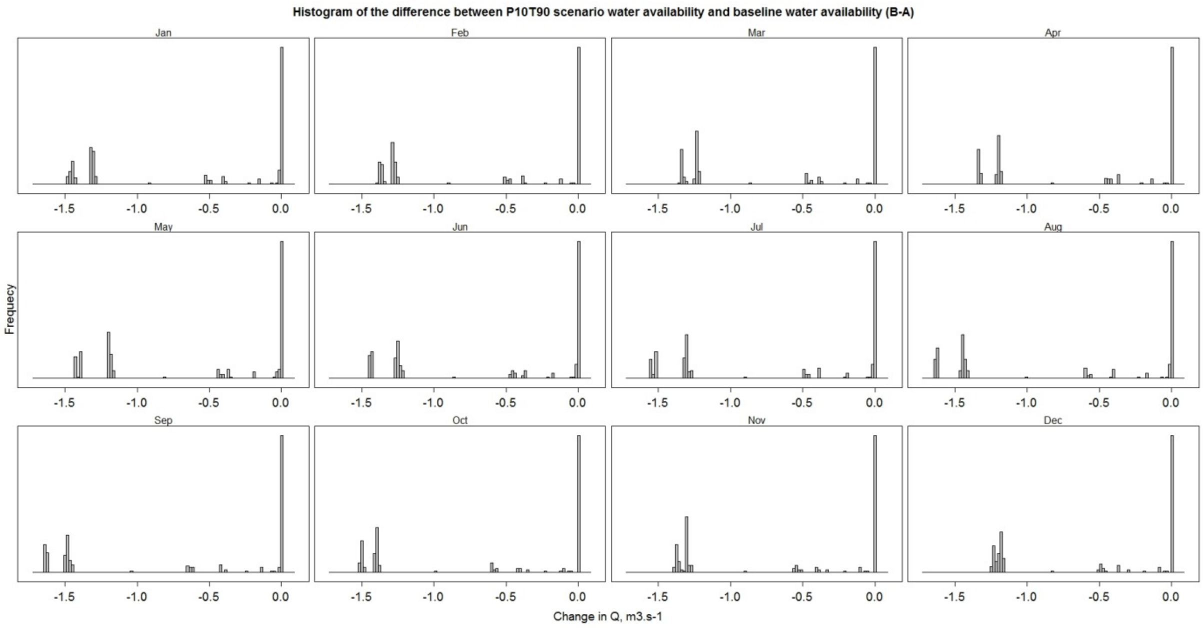

Figure 39. Histogram of the difference between P10T90 scenario water availability and baseline water availability (B-A) at the water abstraction points.

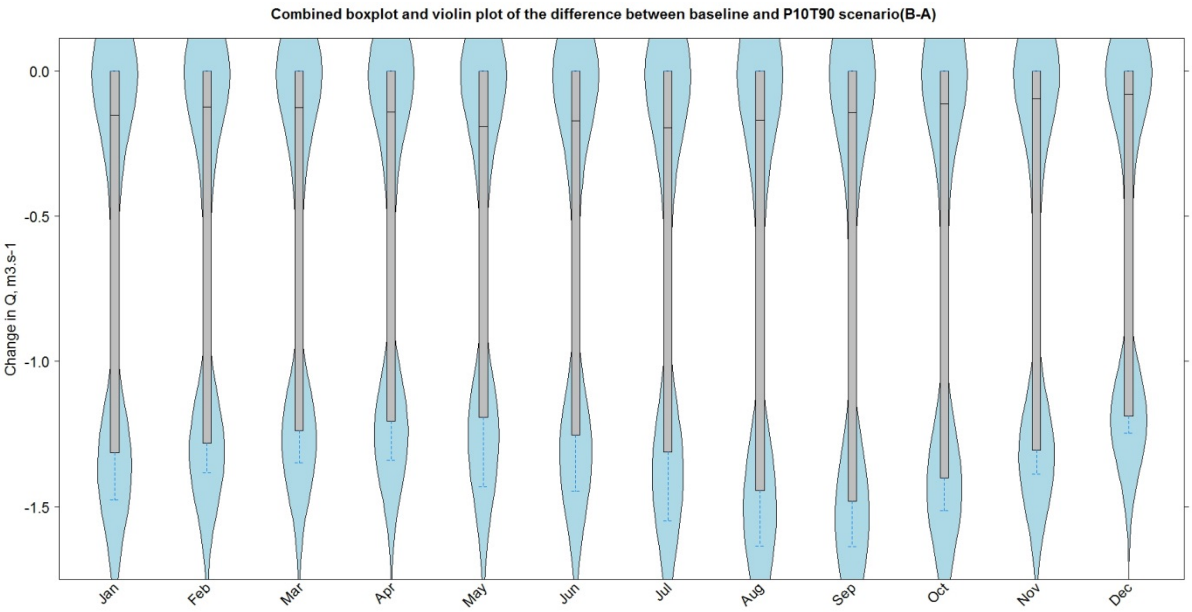

Figure 40. Combined boxplot and violin plot of the difference between P10T90 scenario water availability and baseline water availability (B-A) at the water abstraction points.

For the P10T90 scenario there is a clear bimodal distribution of the differences (looking at Figure 40), with almost as many values around the 0 as between -1.2 and -1.5 m3.s-1. The difference is as much as the mean average flow we simulated for the catchment in the baseline condition, i.e. the simulated decrease in potential water availability is large for the P10T90 scenario. There is little variability between the months.

For the Copiapó river basin case we decided to also include an analysis of the monthly variability in discharge for the future projected scenarios to check if the simulated discharge variability within the future scenario is larger or smaller than the difference between the baseline scenario and the future projected scenario. This was done by subtracting the monthly minimum runoff with the monthly maximum runoff in the two scenarios presented here. Table 5 shows the summary of monthly discharge variation (min-max) and the difference between the P90T10 scenario and baseline scenario (mean monthly values, B-A) at the areas where water abstractions are being made. For the P10T90 scenario, the monthly variability in discharge is smaller than the monthly difference between the P10T90 and baseline scenario. In the P10T90 scenario the flow that is simulated is probably discharge flowing in the subsurface stores (layers 2 and 3) only. This represents minimum flow for which smaller variability between years is expected.

Table 5. Summary of monthly discharge variation and difference between P10T90 scenario discharge to baseline discharge (B-A) at water abstraction areas.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
min-max P10T90	-0.01	-0.01	-0.01	-0.02	-0.14	-0.06	-0.08	-0.06	-0.06	-0.02	-0.02	-0.01	-0.04
(b-a) P10T90	-0.60	-0.57	-0.56	-0.55	-0.56	-0.58	-0.61	-0.66	-0.67	-0.63	-0.58	-0.53	-0.59

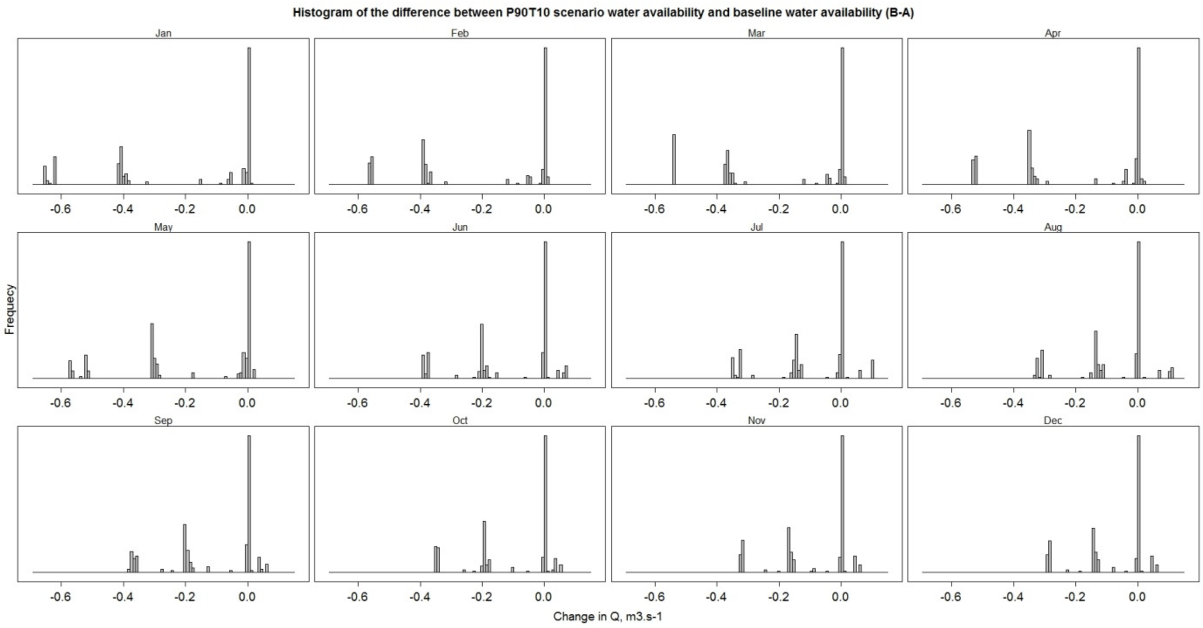

Figure 41. Histogram of the difference between P90T10 scenario water availability and baseline water availability (B-A) at the water abstraction points.

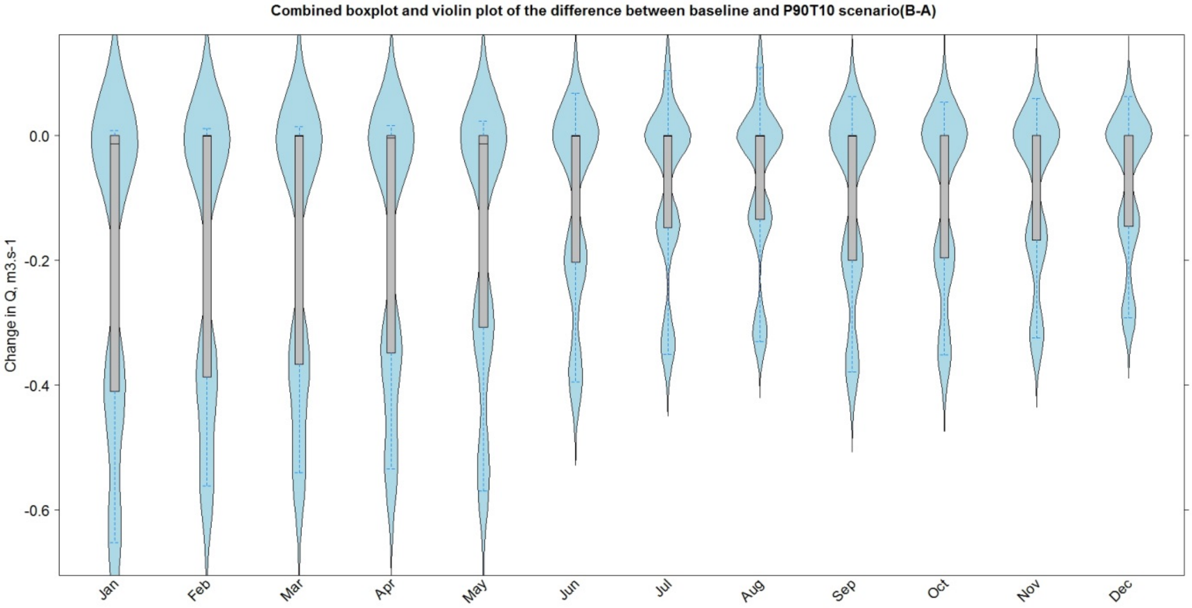

Figure 42. Combined boxplot and violin plot of the difference between P90T10 scenario water availability and baseline water availability (B-A) at the water abstraction points.

In the P90T10 simulations the differences in discharge from the baseline situation are small, with most values centered around 0. The majority of the remaining values are lower than 0, indicating less runoff in a wetter scenario than in the baseline simulation. This might be explained by an increase in evapotranspiration because of increasing temperatures which causes a decrease in potential water availability compared to the baseline simulation, even though a relatively large increase in precipitation (compared to baseline) is used as input in this scenario. The variation between months is completely different between the scenarios: in the P90T10 the period Jan-May will have the possible reductions in available flow; in the P10T90 scenario the months Aug-Oct have the largest potential decrease in available flow.

When comparing variability in discharge and difference between baseline and the P90T10 scenario on a water abstraction area scale, the difference become even more apparent as can be seen in Table 6. This is the opposite situation than with the P10T90 scenario. This might be explained by the relatively large increase in projected precipitation in this scenario which causes more surface runoff with which higher variability is expected.

Table 6. Summary of monthly discharge variation and difference between P90T10 scenario discharge to baseline discharge (B-A) at water abstraction areas.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
min-max P90T10	-1.14	-1.10	-1.06	-1.01	-1.01	-1.08	-0.96	-1.31	-1.34	-1.24	-1.18	-1.08	-1.12
(b-a) P90T10	-0.21	-0.19	-0.18	-0.18	-0.17	-0.11	-0.09	-0.08	-0.11	-0.10	-0.09	-0.08	-0.13

Table 7. Monthly average basin values of the difference between future scenario discharge to baseline discharge (B-A) for the 5 future scenarios

B-A average	P10T90	P90T90	M	P10T10	P90T10	mean
Jan	-0.60	-0.26	-0.55	-0.60	-0.21	-0.44
Feb	-0.57	-0.24	-0.53	-0.57	-0.19	-0.42
Mar	-0.56	-0.23	-0.51	-0.56	-0.18	-0.41
Apr	-0.55	-0.22	-0.49	-0.55	-0.18	-0.40
May	-0.56	-0.21	-0.50	-0.56	-0.17	-0.40
Jun	-0.58	-0.16	-0.52	-0.58	-0.11	-0.39
Jul	-0.61	-0.11	-0.51	-0.61	-0.09	-0.39
Aug	-0.66	-0.14	-0.55	-0.66	-0.08	-0.42
Sep	-0.67	-0.18	-0.58	-0.68	-0.11	-0.44
Oct	-0.63	-0.17	-0.55	-0.63	-0.10	-0.42
Nov	-0.58	-0.16	-0.52	-0.58	-0.09	-0.39
Dec	-0.53	-0.14	-0.47	-0.53	-0.08	-0.35
mean	-0.60	-0.16	-0.53	-0.60	-0.10	

Table 7 presents average statistics for all the months and water extraction points in the Copiapó river basin. All scenarios and all months give negative values, i.e. a decrease in potential water availability. For the scenarios predicting an increase in future precipitation (P90T90 and P90T10), the decrease in potential water availability can be explained by an increase in potential evapotranspiration and the fact that the absolute increase in precipitation is small.

2.5.2.4 Mexico

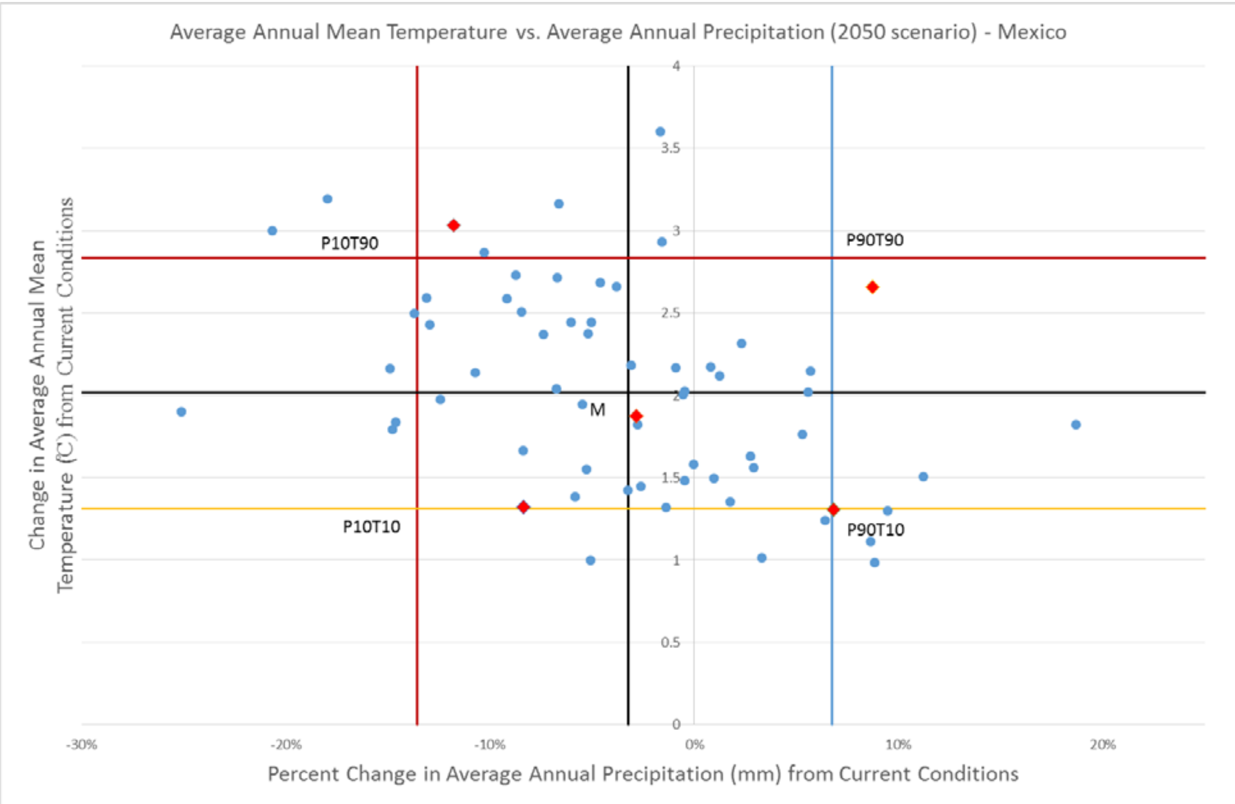

Figure 43. Five future climatic models which were selected from 63 climatic models for Rio Grande/Bravo Lower Basin, Mexico.

Figure 43 shows the 5 selected GCM and RCP for the Rio Grande/Bravo Lower Basin, Mexico site. A majority of the GCMs simulate an annual decrease in precipitation while an increase in temperature is simulated for all the GCMs.

The land use in the Rio Grande/Bravo Lower Basin is depicted in Figure 44. Most of the land use consists of agriculture, irrigated or non-irrigated. In the North a few urban areas can be found.

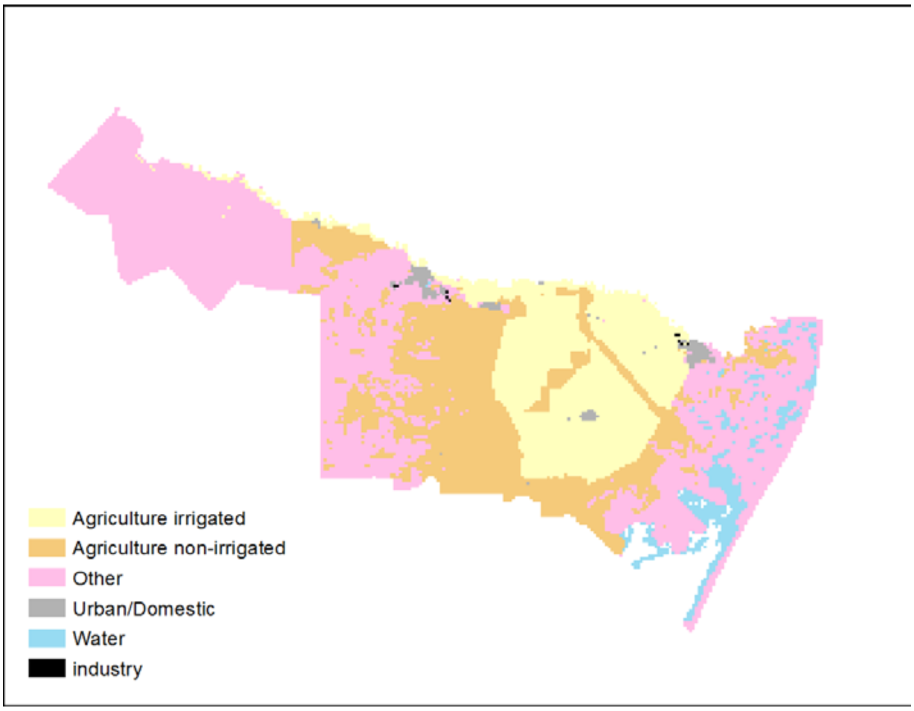

Figure 44. Land use map of the Rio Grande/Bravo Lower Basin, Mexico.

Figure 45 shows the historical mean monthly precipitation and temperature for Rio Grande, Mexico from the 1950-2000 period. This figure has been constructed by calculating mean temperature and precipitation from the downloaded WorldClim climatic raster maps for the historical period, i.e. these are average data for the whole catchments and not from a point measurements.

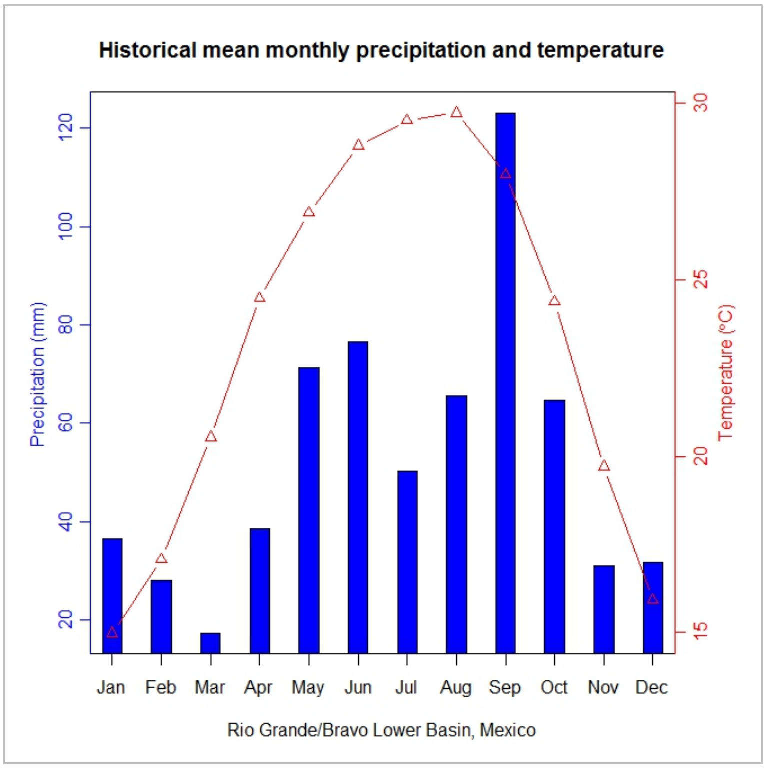

Figure 45. Mean monthly precipitation and temperature for the Rio Grande, Mexico.

Figure 46 shows the summary of comparison between baseline mean discharge and P10T90 scenario mean discharge for all seasons. The difference is calculated on a cell to cell basis where the future projected scenario is divided with the baseline scenario. Values below 1 represent a decrease in water availability (red colours); values higher than 1 represent an increase in water availability (blue colours), while values around 1 represent no or little change (white).

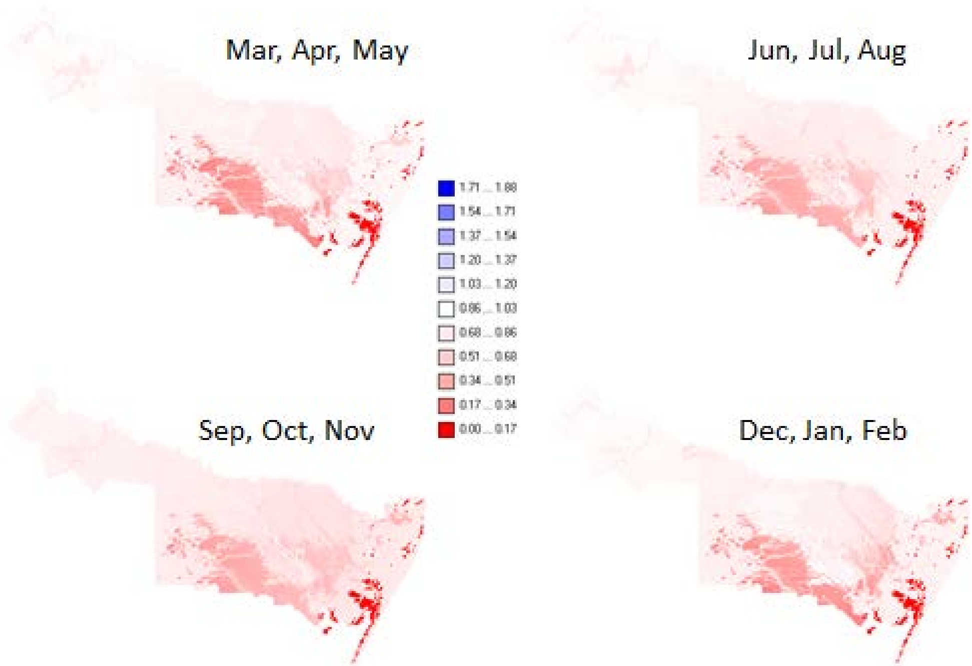

Figure 46. Ratio of P10T90 scenario discharge to baseline discharge (B/A) for all the seasons in the Rio Grande/Bravo Lower Basin, Mexico

Figure 46 shows the relative change in water availability for P10T90 scenario and the different seasons. The dark read pixels in the eastern part of the basin represent the land use "water". The water availability of the land use "water" obtains a value of 0 both in the baseline and scenario model runs and can be ignored for the purpose of the comparison.

A decrease in water availability is simulated for all the seasons across the whole basin. An especially large decrease in water availability is projected for the southern parts of the area where we find the land use "agriculture non-irrigated". This could be related to the lower crop coefficient attributed to this type of land cover (0.9 versus 1.2 for irrigated crops in the growing season).

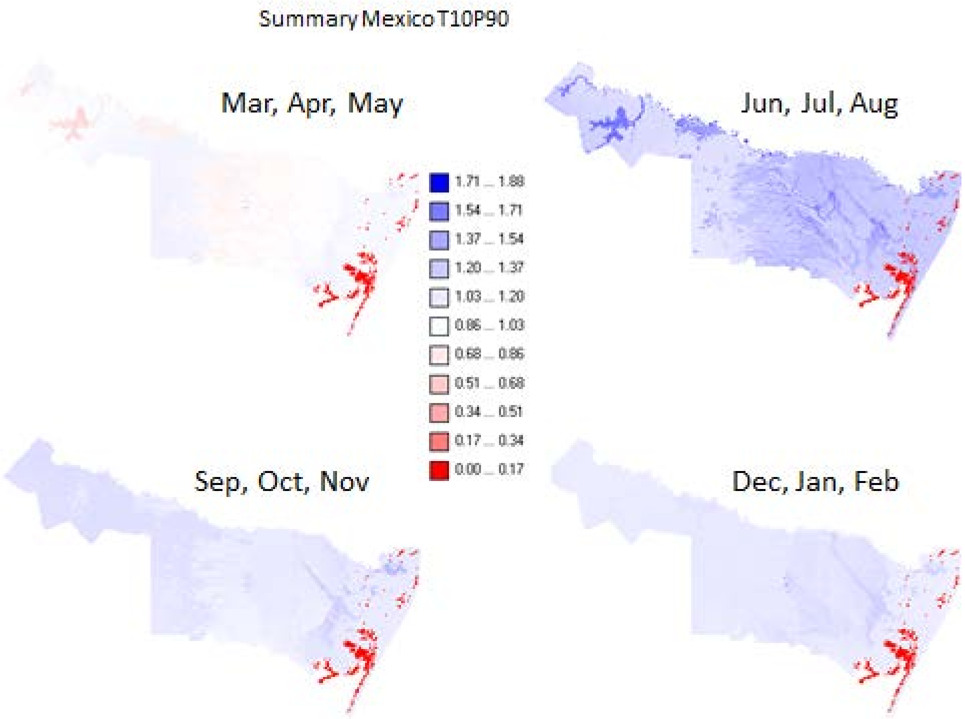

Figure 47. Ratio of P90T10 scenario discharge to baseline discharge (B/A) for all the seasons in the Rio Grande/Bravo Lower Basin, Mexico

Figure 47 shows the relative change in water availability for P90T10 scenario and the different seasons. For all the seasons, except the March-May season, an increase of water availability in the P90T10 scenario is projected. A 28% increase in water availability is projected for the June-August period. For the March-May period, the largest decrease is projected in some areas of the western parts of the basin, together with a slight decrease in the central part of the basin associated with agriculture. However, the decrease in the March-May period is small overall.

Table 8. Mean statistics of the ratios of scenario discharge to baseline discharge (B/A) for the 5 future scenarios

B/A average	P10T90	P90T90	M	P10T10	P90T10	mean
Mar, Apr, May	0.787	1.152	0.893	0.783	0.939	0.911
Jun, Jul, Aug	0.778	0.982	0.889	0.772	1.288	0.942
Sep, Oct, Nov	0.733	1.359	0.934	0.878	1.106	1.002
Dec, Jan, Feb	0.778	1.055	0.913	0.987	1.099	0.969
mean	0.769	1.137	0.907	0.855	1.111	

Table 8 shows the mean statistics for the relative change in potential water availability for all the scenarios in the Rio Grande/Bravo Lower Basin, Mexico. All scenarios, except the P90T90 and P90T10 scenario, simulate a decrease in potential water availability.

2.5.3 Green versus blue water availability

At the global scale, the dominant source of freshwater is green water flow, i.e. the rainfall that infiltrates in the upper unsaturated soil layers and flows back to the atmosphere as vapor and evapotranspiration (Falkenmark & Rockström, 2010b). According to (Falkenmark & Rockström, 2010b), blue water, i.e. the freshwater contained in rivers, lakes, reservoirs and the groundwater, derives from 35% of the continental precipitation, whereas 65% of this precipitation is converted to green water. Based on this fact, Falkenmark and Rockström (2010b) call for a shift in perspective in water resources management by considering precipitation as an important water source in governance and management. Soil management and land use can be used to influence the partitioning of rainwater between green water in the soil and blue water in rivers and aquifers, both in areas used for agriculture or urban land use types. Combining measures for soil and land management with options for water reuse schemes in river basins could lead to flexible and innovative strategies to govern and manage fresh and grey water resources in river basins.

The WP4-tool can be used to generate information on the proportion between available green and blue water under various conditions of climate and land use. The actual evapotranspiration from bare soil and vegetated surfaces simulated by the PCRGLOBWB model at given locations in a river basin can be considered as the green water flow, whereas the discharge simulated by the model can be considered as the blue water flow, since it combines the flows generated in the three stores of the soil-substrate column (see Figure 8). It should be noted that in this concept, the freshwater stored in the aquifers and reservoir, that is not transferred from a grid cell in a model simulation, is not considered as 'available' flow. Both types of flow can be aggregated to areas within the river basin of particular interest, such as areas destined for a particular land use (e.g. settlements with green infrastructure or forest plantations). In Figure 48 we show the average proportions between available green and blue water on an annual basis for the four COROADO case study areas under the climate conditions of the baseline period (2000-2010), and of the five scenarios of climate change. The following observations can be made from the figure:

- Green water flow constitutes the larger part of the available fresh water in the areas in Argentina and Chile (resp. 65-70% and 90-100%). In the area in Brazil blue water is the larger part of the available flow (50-62%).
- In the area in Mexico green and blue water flow make up equal portions of the available flow, and the proportion between the two types of flow does not vary much between scenarios. However, this is due to the fact that the inflow from the Falcon reservoir was modelled according to the baseline simulation in all scenarios.
- Changes in the proportion between green and blue water flows under different scenarios of climate change are marginal; at most 8% in either direction. Considering that the spatial distribution of land use and land cover was kept as in the baseline situation for all scenarios, this indicates that climate change only has a minor influence on the partitioning of green and blue water flows, and that there is scope for improving the use of available green water through soil management and land use change.

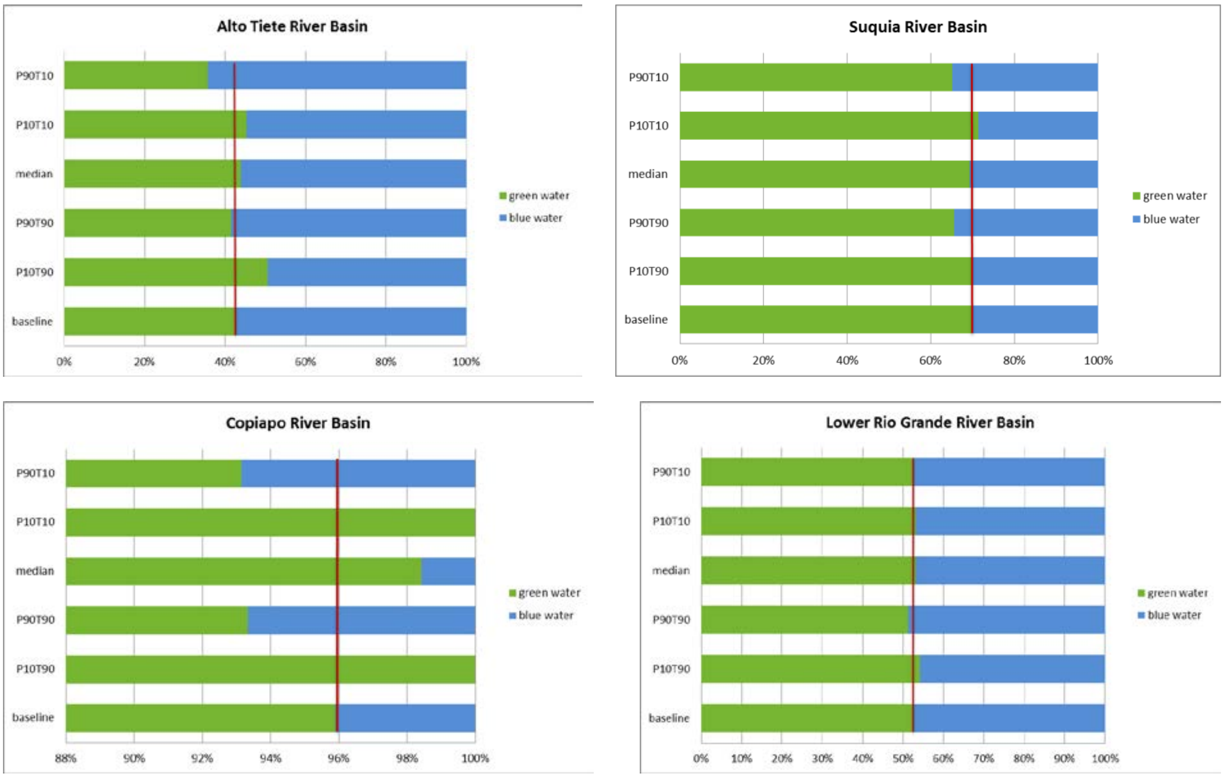

Figure 48 Proportions between green and blue water in the four case study areas under baseline conditions (2000-2010) and conditions of climate change (around 2050). % refers to the sum of green and blue available water; change in storage is excluded. Red vertical line indicates the proportion between green and blue water under baseline conditions. Note the adapted scale on the x-axis for the Copiapo River Basin in Chile.

2.6 Assessment of blue and green water availability under scenarios of climate change: regional domain

2.6.1 Method

Future climatic scenario selection for the regional Latin America domain was done by the same procedure as for the local basins (chapter 2.5). First, Latin America was divided into seven different regions (Figure 49) and five different GCMs where chosen for each of these regions (Table 9). The seven different regions were aggregated into one in the model run, leaving five scenarios to be analyzed for the whole of Latin America.

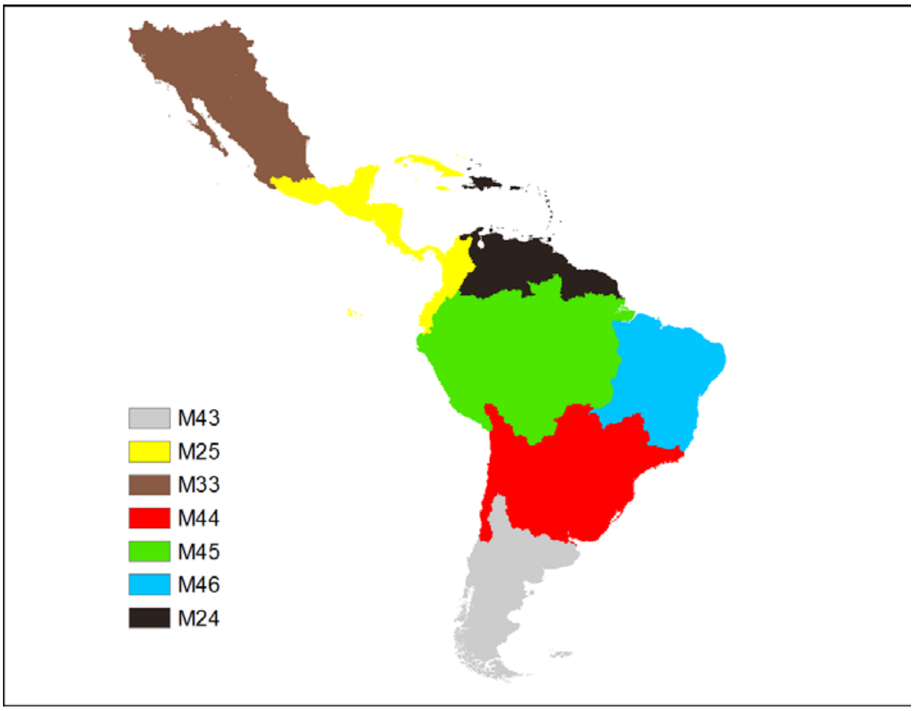

Figure 49. The seven regions of Latin America used during the selection of the future climatic scenarios.
Table 9. The different climatic models (per region) which represent the 5 scenarios. The first two letters are abbreviations for the model, the latter two numbers represent the RCP (http://www.worldclim.org/).

Model Scenario	M24	M25	M33	M43	M44	M45	M46
Median (M)	he26	cn85	hd45	mi45	cc45	cn85	ac45
Hotter and wetter (T90P90)	mi85	mi85	hd85	cn85	bc85	ce45	hg45
Hotter and drier (P10T90)	he60	ip45	mc85	mi85	mr85	he85	mi85
Warmer and drier (P10T10)	no60	no60	gs85	gd45	gd26	gs26	gs26
Warmer and wetter (P90T10)	mg45	gd26	mi26	mg45	gs85	in85	no60

Figure 50 represent maps with the relative change in mean monthly discharge for Latin America according to the regional domain modeling results for the T90P10 scenario and for the T10P90 scenario respectively. The relative change maps are basically constructed by calculating the relative difference between a scenario and the baseline situation ((scenario – baseline)/ baseline*100). Negative values (darker colors) mean that the modelled discharge in the scenario simulation is less than the modelled discharge in the baseline simulation. Positive values (lighter colors) mean an increase in the modelled scenario discharge compared to the baseline discharge.

Instead of presenting all five scenarios in this report, it was decided to only present the relative change in the mean monthly discharge for two scenarios. T90P10 is a dry scenario and T10P90 is a wet scenario. All five scenarios are presented in Annex 1.7. However, consider that different effects may occur for specific regions within the domain opposite of what might be expected in the scenario.

2.6.2 Results

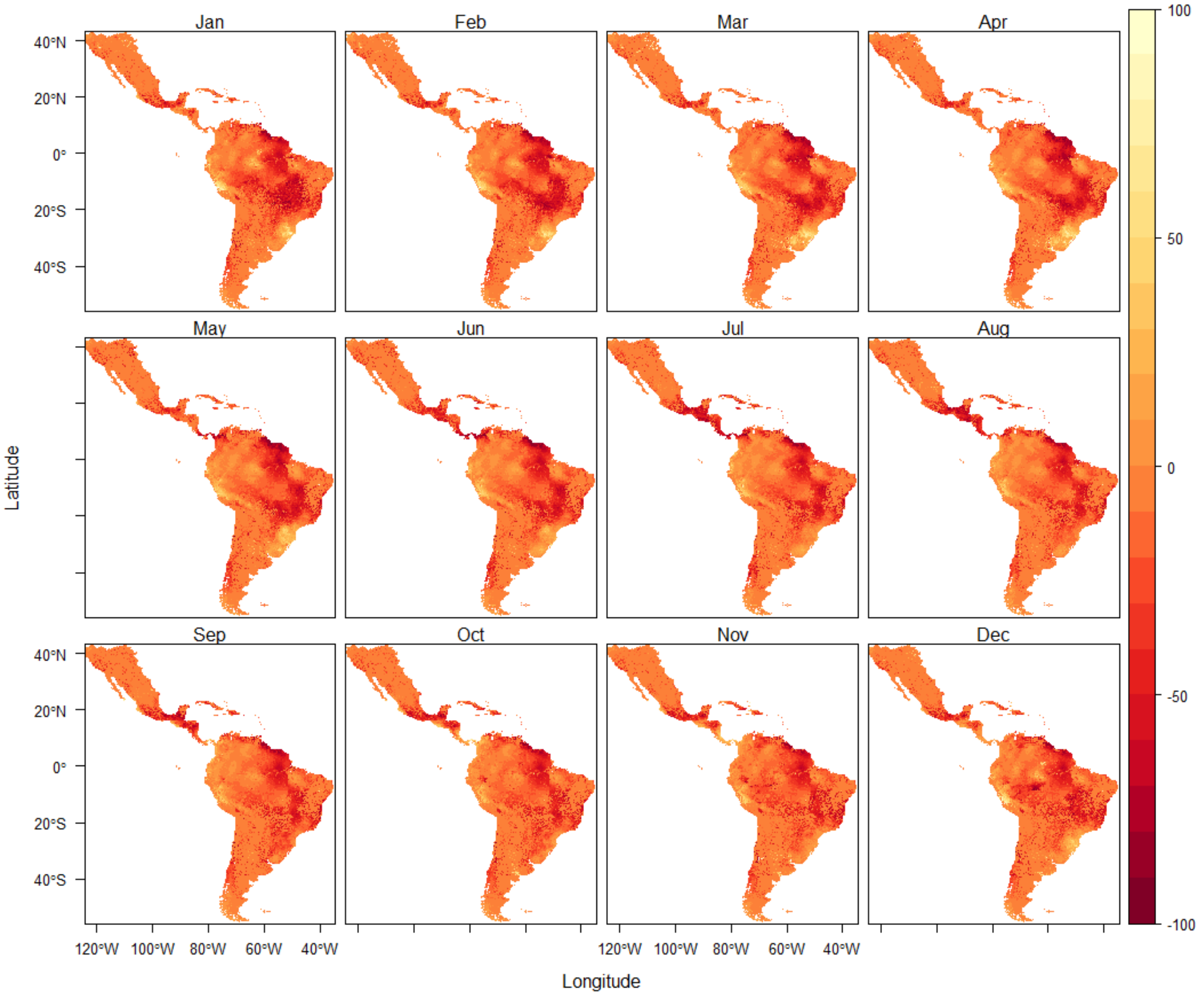

Figure 50. Maps with relative change in mean monthly discharge per month for Latin America according to the regional domain modeling results for the T90P10 scenario 'minus' the baseline situation.

In accordance with the expectations, the scenario T90P10 generally produces less discharge compared to the baseline. This is illustrated by the primarily darker colors in Figure 50. Notice however that some areas have a simulated increase in mean monthly discharge compared to the baseline. This is because projected change in rainfall and temperature will vary geographically (and thus discharge will vary geographically).

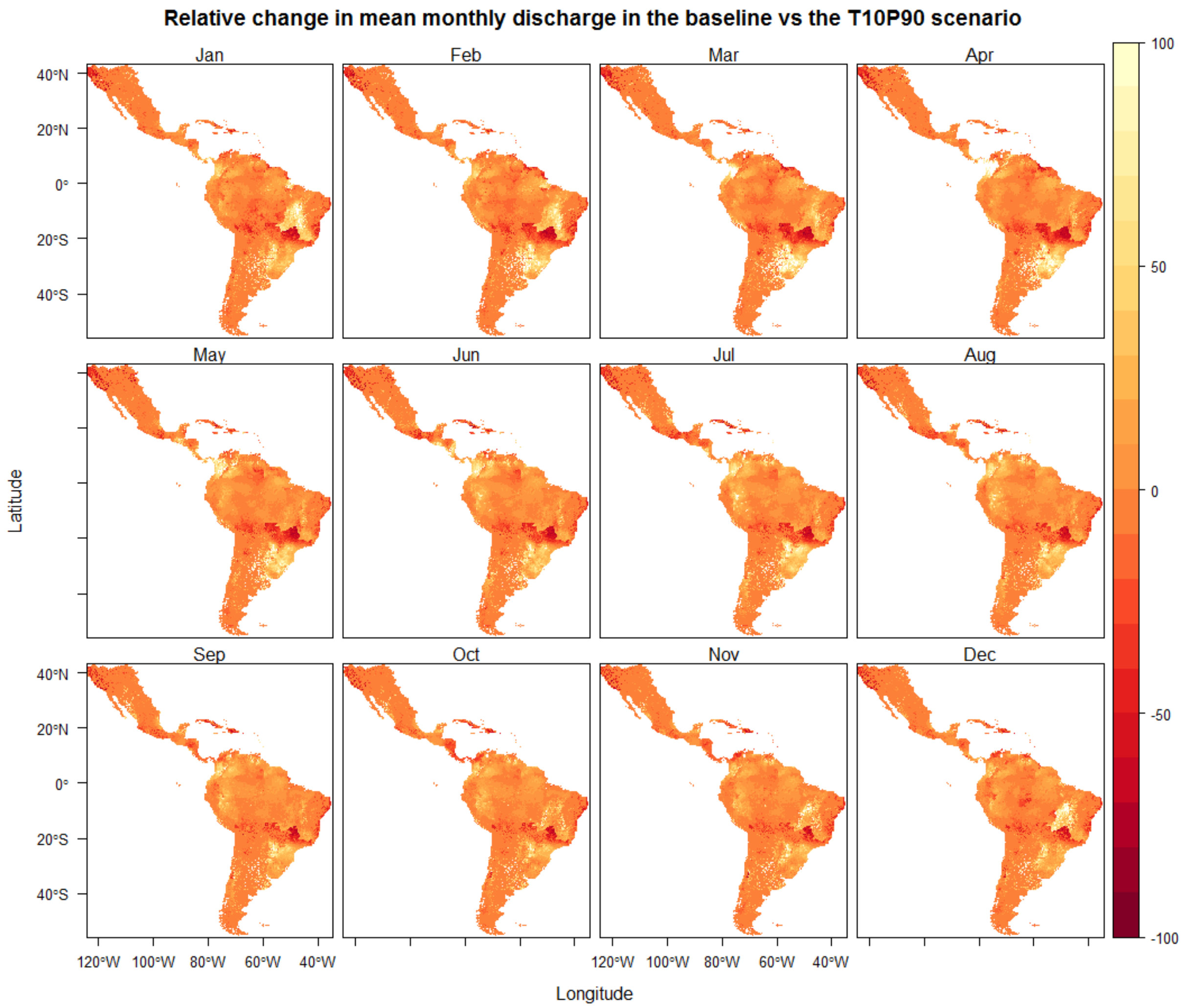

Figure 51. Maps with relative change in mean monthly discharge per month for Latin America according to the regional domain modeling results for the T10P90 scenario 'minus' the baseline situation.

As expected, the scenario T10P90 produces more discharge compared to the baseline (judging by the lighter colors in Figure 51). However, in this scenario there are also a few regions with decreasing mean monthly discharge compared to the baseline. The relative change in mean monthly discharge varies geographically due to variation in the projected future precipitation and temperatures.

The IPCC report on regional aspects of climate change (IPCC, 2014) summarized the observed changes in runoff for the different regions of Latin America as follows (Figure 27-7 in the IPCC report):

- Central America (CA) and northern South America (NSA): decrease
- Amazonia (AMA): increase and decrease (no consistent change)
- Tropical Andes (TAnd): seasonality change
- Central Andes (Cand): decrease and a seasonality change
- Northeast Brazil (NE): decrease
- Southeastern South America (SESA): increase

It is difficult to compare the simulation results with Barros et al. (2014), because the variation within the regions in the scenario simulation results is very high. Most scenarios (except T90P90) expect less discharge in CA like Barros et al. (2014). The decrease in NSA according to Barros et al. (2014) is not so explicit in our scenarios. The AMA region shows a lot of variation (some parts show an increasing discharge, others a decreasing discharge) in our scenarios. There seems to be a slight tendency towards decreasing discharge in the Central Andes in our simulations. The NE region presents a lot of variation in the simulated discharge: some parts of NE show an increasing discharge (lighter colours), others an decreasing discharge (darker colours). Based on the scenario simulations it is hard to confirm the findings of Barros et al. (2014) for this region. In the wetter scenario simulations (P90) there seems to be an increase in discharge in the SESA region (like Barros et al., 2014). In the other scenario simulations the variations within the region are too large to make a clear statement.

For every scenario an overall mean monthly discharge is calculated from the maps. These overall monthly scenario discharges are divided by the corresponding overall monthly baseline discharge. The resulting ratio is presented in table Table 10. Generally, scenario T90P90 (Hotter Wetter) is the wettest scenario and T10P10 (Warmer Drier) is the driest scenario. The differences between the scenarios are only the result of different climatic scenarios (precipitation, evapotranspiration and temperature). All other model input (e.g. land use) remain the same in all scenarios and the baseline.

Table 10. Mean statistics of the ratios scenario discharge divided by baseline discharge for the 5 future climatic scenarios.

	T90P10	T90P90	M	T10P10	T10P90
Mean	0.87	1.14	0.96	0.84	1.04

2.7 References

Candogan Yossef, N., van Beek, L. P. H., Kwadijk, J. C. J., & Bierkens, M. F. P. (2012). Assessment of the potential forecasting skill of a global hydrological model in reproducing the occurrence of monthly flow extremes. *Hydrology and Earth System Sciences*, *16*(11), 4233–4246. doi:10.5194/hess-16-4233-2012

Chang, N.-B., Yang, Y. J., Goodrich, J. a, & Daranpob, A. (2010). Development of the Metropolitan Water Availability Index (MWAI) and short-term assessment with multi-scale remote sensing technologies. *Journal of Environmental Management*, *91*(6), 1397–413. doi:10.1016/j.jenvman.2010.02.024

Cmy, C. Y. (2006). Handbook on feasibility studies for water reuse systems w w w . a q u a r e c . o r g, (February).

Cossavella, A. M. (2013). *Estándares de calidad de agua y preservación de los recursos hídricos Cuenca rio Primero (Suquía) y río Segundo (Xanaes)*. Cordoba, Argentina: Presentation in the plenary meeting of the COROADO project, 27-11-2013, Cordóba, Argentina.

De Graaf, I. E. M., van Beek, L. P. H., Wada, Y., & Bierkens, M. F. P. (2014). Dynamic attribution of global water demand to surface water and groundwater resources: Effects of abstractions and return flows on river discharges. *Advances in Water Resources*, *64*, 21–33. doi:10.1016/j.advwatres.2013.12.002

Falkenmark, M., & Rockström, J. (2010a). Building Water Resilience in the Face of Global Change: From a Blue-Only to a Green-Blue Water Approach to Land-Water Management. *Journal of Water Resources Planning and Management*.

Falkenmark, M., & Rockström, J. (2010b). Building Water Resilience in the Face of Global Change: From a Blue-Only to a Green-Blue Water Approach to Land-Water Management. *Journal of Water Resources Planning and Management*.

FAO. (2014). *AQUASTAT Database*. Retrieved from http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

Galli, G. (2014). Towards systemic change in urban sanitation be a surprise or cause for celebration ., (November).

García, L. E., Matthews, J. H., Rodriguez, D. J., Wijnen, M., DiFrancesco, K. H., & Ray, P. (2014). *Beyond ownscaling: a Bottom-up Approach to Climate Adaptation for Water Resources Management*.

Washington DC: World Ban Group. Retrieved from http://alliance4water.org/resources/AGWA_Beyond_Downscaling.pdf

Hamouda, M. A., Anderson, W. B., & Huck, P. M. (2009). Decision support systems in water and wastewater treatment process selection and design: a review. *Water Science & Technology*. Retrieved from http://www.iwaponline.com/wst/06007/wst060071757.htm

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*(15), 1965–1978. Retrieved from http://doi.wiley.com/10.1002/joc.1276

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. (n.d.). *The Water Footprint Assessment Manual*.

IPCC. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 688 pp). Retrieved from https://ipcc-wg2.gov/AR5/report/full-report/

Jiménez, B. (2008). Water reuse in Latin America and the Caribbean. Retrieved from http://books.google.com/books?hl=en&lr=&id=zYcTnBmZeIcC&oi=fnd&pg=PA177&dq=Water+reuse+in+Latin+America+and+the+Caribbean&ots=Xx6V7afmT9&sig=bWntRFD642lu0JI6UI9eoyu1cGM

Ligtvoet, W., & Hilderink, H. (2014). *Towards a world of cities in 2050 An outlook on water- related challenges - Background report to the UN-Habitat Global Report* (p. 76). Retrieved from http://www.pbl.nl/sites/default/files/cms/PBL_2014_Towards a world of cities in 2050_1325.pdf?utm_source=DMdelivery&utm_medium=email&utm_content=download het rapport %28Engelsta&utm_campaign=PBL-nieuwsbrief 6 oktober 2014

Meted.ucar.edu. (2012). *Preparing Hydro-climate Inputs for Climate Change in Water Resource Planning*. Retrieved November 12, 2014, from http://www.meted.ucar.edu/USBR/water_climate/navmenu.php?tab=1&page=1.2.0&type=text

New, M., Hulme, M., & Jones, P. D. (2000). Representing twentieth century space-time climate variability. Part 2: Development of 1901–96 monthly grids of terrestrial surface climate,. *J. Clim.*, *13*, 2217–2238.

New, M., Hulme, M., & Jones, R. D. (1999). Representing twentieth century space-time climate variability. Part 1: Development of a 1961–90 mean monthly terrestrial climatology. *J. Clim.*, *12*, 829–856. doi:10.1175/1520-0442(1999)012<0829:RTCSTC>2.0.CO;2

Porto, M. F. A., & Dalcanale, F. (2014). *D2.2. Synthesis report & mapping of water reuse and recycling technologies, launch of the COROADO-web tool* (p. 60).

Porto, M. F. A., Dalcanale, F., Mierzwa, J. C., Rodrigues, L. D. B., Pio, A., Gironás, J., … Reyna, S. (2012). *Coroado project DL2.1 - Report on the Context of the Areas, Workshop Structure, and Development*.

Sperna Weiland, F. C., Tisseuil, C., Dürr, H. H., Vrac, M., & van Beek, L. P. H. (2012). Selecting the optimal method to calculate daily global reference potential evaporation from CFSR reanalysis data for application in a hydrological model study. *Hydrology and Earth System Sciences*, *16*(3), 983–1000. doi:10.5194/hess-16-983-2012

Suárez, F., Muñoz, J. F., Fernández, B., Dorsaz, J.-M., Hunter, C. K., Karavitis, C. A., & Gironás, J. (2014). Integrated Water Resource Management and Energy Requirements for Water Supply in the Copiapó River Basin, Chile. *Water*, *6*(9), 2590–2613. doi:10.3390/w6092590

Tosselli, L. E. (2013). *EL RIEGO EN CORDOBA CAPITAL. Secretaria de Recursos Hídricos y Coordinación, Prof. Asistente Cátedra de Obras Hidráulicas – FCEFyN – UNC.* Cordoba, Argentina: Presentation in the plenary meeting of the COROADO project, 27-11-2013, Cordóba, Argentina.

UN. (2014). *The United Nations World Water Development Report 2014: Water and Energy.* (Vol. 1, p. 230). UNESCO, Paris. Retrieved from http://unesdoc.unesco.org/images/0022/002257/225741E.pdf

UN-Habitat. (2012). *State of latin american and caribbean cities 2012*.

Urkiaga, A., Fuentes, L. de las, Bis, B., Hernández, F., Koksis, T., Balasz, B., … Melin, T. (2006). *Handbook on feasibility studies for water reuse systems* (p. 159).

Van Beek, L. P. H., & Bierkens, M. F. P. (2009). *The Global Hydrological Model PCR-GLOBWB : Conceptualization , Parameterization and Verification* (p. 53). Retrieved from http://vanbeek.geo.uu.nl/suppinfo/vanbeekbierkens2009.pdf

Van Beek, L. P. H., Wada, Y., & Bierkens, M. F. P. (2011a). Global monthly water stress: 1. Water balance and water availability. *Water Resources Research*, *47*(7), n/a–n/a. doi:10.1029/2010WR009791

Van Beek, L. P. H., Wada, Y., & Bierkens, M. F. P. (2011b). Global monthly water stress: 1. Water balance and water availability. *Water Resources Research*, *47*(7), n/a–n/a. doi:10.1029/2010WR009791

Van der Bliek, J., McCornick, M., & Clarke, J. (2014). *On target for people and planet: setting and achieving water-related sustainable development goals* (p. 56). International Water Management Institute (IWMI). doi:10.5337/2014.226

Verzandvoort, S. (Alterra-W. U., Oertlé, E. (FHNW), Gross, T. (FHNW), Heesmans, H. (Alterra-W. U., Stolte, J. (BIOFORSK), & Eggen, G. (BIOFORSK). (2013). *Report on reuse & recycling technologies & sanitation practices related to current & future needs* (p. 100). Wageningen, Netherlands.

Wada, Y., Beek, L. P. H. Van, & Bierkens, M. F. P. (2011). Supplementary material to " Modelling global water stress of the recent past : on the relative importance of trends in water demand and climate variability ", (December), 1–12.

Wada, Y., van Beek, L. P. H., & Bierkens, M. F. P. (2011). Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability. *Hydrology and Earth System Sciences*, *15*(12), 3785–3808. doi:10.5194/hess-15-3785-2011

Wada, Y., van Beek, L. P. H., & Bierkens, M. F. P. (2012). Nonsustainable groundwater sustaining irrigation: A global assessment. *Water Resources Research*, *48*(November 2011), W00L06. doi:10.1029/2011WR010562

Wada, Y., van Beek, L. P. H., Viviroli, D., Dürr, H. H., Weingartner, R., & Bierkens, M. F. P. (2011). Global monthly water stress: 2. Water demand and severity of water stress. *Water Resources Research*, *47*(7), n/a–n/a. doi:10.1029/2010WR009792

Wintgens, T., & Hochstrat, R. (2006). *Integrated Concepts for Reuse of Upgraded Wastewater*. (T. Wintgens & R. Hochstrat, Eds.) (pp. 1–184). Aquarec.

WorldClim. (2011). *WorldClim - Global Climate Data: Free climate data for ecological modeling and GIS*. Retrieved from http://www.worldclim.org/

Yang, H., Pfister, S., & Bhaduri, A. (2013). Accounting for a scarce resource: virtual water and water footprint in the global water system. *Current Opinion in Environmental Sustainability*, *5*(6), 599–606. doi:10.1016/j.cosust.2013.10.003

3 Water demand assessment (Module 2)

3.1 Introduction

Water demand is defined as the water that would be used by a given activity or sector if sufficient water would be available (e.g. (Yoshihide Wada et al., 2011a)). Following (Yoshihide Wada et al., 2011b), we distinguish gross and net water demand. Gross water demand is the total water demand, including the water that is recycled and returned to the environment after use (within or outside of the region considered). Part of the water returned to the environment is recoverable, which means that it can be captured and reused (i.e. the non-consumed recoverable water quantity). This part is of interest to water reuse & recycling applications. Another part of the return flow comprises water that is neither beneficially consumed, nor available or suitable for further use (i.e. the non-consumed, non-recoverable water quantity). Examples are discharge to saline sinks, saline groundwater, or to the sea (Frederiksen, 2011). This type of return flow occurs in all case study sites: discharge to saline groundwater in Argentina, Brazil and Mexico, discharge to the sea in Mexico, and evapotranspiration of water withdrawn from the groundwater in Chile.

Net water demand includes the consumptive water use for domestic purposes, industry, agriculture and ecosystems. Part of this water is returned to the atmosphere by evapotranspiration, and part of it is embodied in organisms and products, which can be moved or traded outside the region of interest as 'virtual water' (Hoekstra, Chapagain, Aldaya, & Mekonnen, n.d.), (Yang, Pfister, & Bhaduri, 2013). The net water demand does not include the component of evapotranspiration supplied by precipitation internal to the service area or user, but applies only to withdrawn water from blue water sources (Frederiksen, 2011).

In global studies on water scarcity and water stress, water demand for economic sectors is often estimated from key characteristics of the economic sectors. For agriculture, it is often estimated from the extent of irrigated areas and livestock density (Gleeson, Wada, Bierkens, & van Beek, 2012), (Yoshihide Wada et al., 2011a), (Biemans, 2012). Industrial and domestic water demand can be estimated from the GDP, energy consumption and electricity production (Y. Wada, van Beek, & Bierkens, 2011). The models used to estimate water demand at global scale usually have a support[1] large enough to justify the assumption that transport of water in water systems remains within a grid cell (e.g. 0.5° resolution (approx. 50*50 km^2) in the global studies of (Vorosmarty, 2000) and (Yoshihide Wada et al., 2011a)). However, for the spatial planning of water reuse & recycling schemes, which the WP4-tool should support, the transport pathways must be considered from points of abstraction to water users, from water users to treatment facilities or points or release (return flows), and from treatment facilities to locations of water reuse (Figure 1). In river basins of the size considered in the COROADO project (ca 8000- 20.000 km^2), the distances of these pathways are typically smaller than the model support of global models for water demand. For example, in the study area in Argentina, water is supplied from the San Roque and Los Molinos reservoirs to water purification plants or directly to irrigation zones at some 15-30 km distance (Figure 2). From the locations of use, i.e. in the city and in the irrigated zones, wastewater is returned to the Bajo Grande water treatment plant, the groundwater and the Suquía River within distances also less than 30 km. If we would map water demand in this area using the algorithms developed for the global models, at a spatial resolution of 50*50 km^2, we would not be able to identify areas at risk of water scarcity at sufficient detail to support the spatial planning of water reuse systems, since the locations of water supply points, treatment facilities and water users could be included in a single cell. For this reason, in the WP4-tool we use the observed gross water withdrawal by economic sectors in the region of interest as a proxy for the water demand.

There is another reason to substitute water withdrawals in place of water demand: water demand varies between societies, cultures, and regions, and therefore the term is subjective (Rijsberman 2006) and using it as a variable can lead to inaccurate assessments. For this reason, several water scarcity indices consider water withdrawal in place of water demand (e.g. Raskin et al., 1997; (Y. Wada et al., 2011); Vorosmarty, et al. 2005).

[1] The model support is defined as the dimension of a model unit (De Gruijter, Brus, Knotters, & Bierkens, 2005).

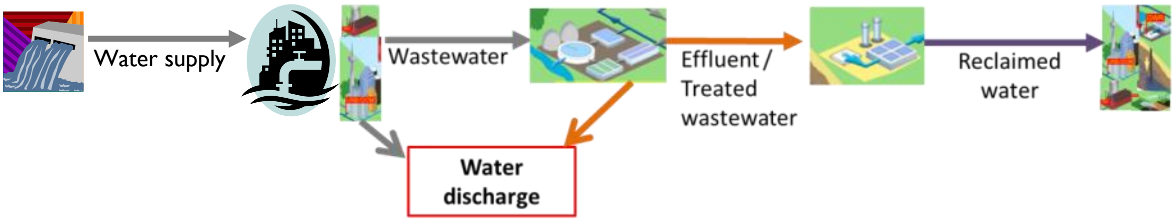

Figure 1 Typical pathways of water in a water reuse & recycling scheme. Adapted from FHNW.

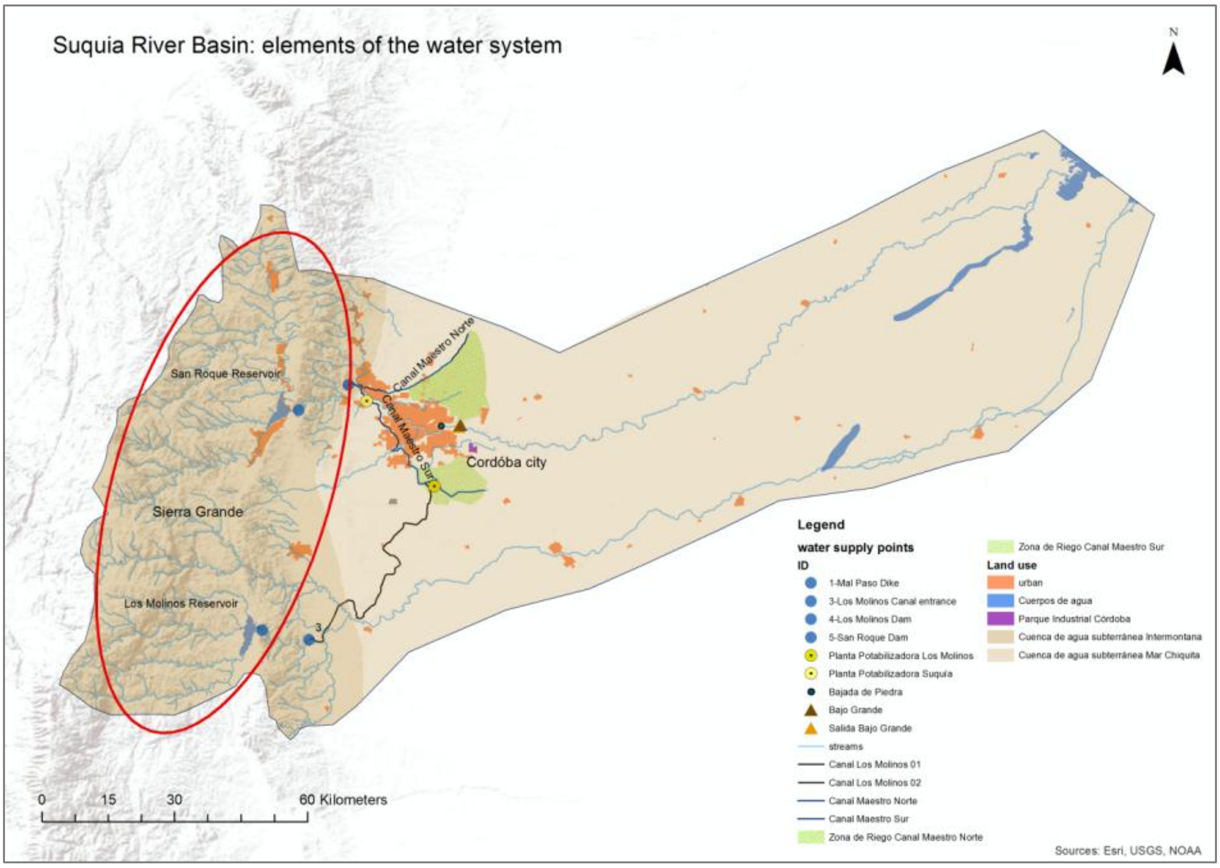

Figure 2 Locations of water supply points, treatment facilities and water users in Suquía River Basin, Argentina . The red ellipse indicates the source area for the surface water supply to the water users in the downstream part of the river basin (a.o. Cordoba city and the irrigated zones around the city).

3.2 The Water Demand Assessment Tool

For the mapping of gross water withdrawal by economic sector, the WP4-tool uses scripts, maps and tables created using the PCRaster Package (http://pcraster.geo.uu.nl/pcraster/4.0.0/doc/manual/secintro.html). PCRaster is a Geographical Information System which consists of a set of computer tools for storing, manipulating, analyzing and retrieving geographic information. The central module of the PCRaster system is the group of PCRaster operations where the operations for Cartographic Modelling are integrated at a high level with the GIS functions of the package. The main GIS functions supported are user interfaces (screen display), conversion of data with other GIS packages and database management. Spatial data are stored in the database as PCRaster maps, a binary format used for representation of raster maps in PCRaster. This format can be read by ArcGIS. The Cartographic Modelling part consist of operators for the static analysis of maps.

The WP4 Water Demand Assessment Tool is a static script written in the PCRaster Cartographic Modelling Language (Annex 1.9), in combination with maps indicating the locations of urban and domestic water use, industrial water use, agricultural water use and water use for mining (the water user zones maps), and lookup tables with the annual gross water withdrawal in $m^3.s^{-1}$ per use type from surface water and groundwater. On running the script, the gross water withdrawal is assigned to the different water user zones according to the numbers on gross water withdrawal from the lookup tables, and divided by 12 to obtain the monthly water withdrawal. This was done to allow for a monthly temporal resolution for the water stress assessment in Module 3, even though information on water withdrawal in the case study sites was not available at a monthly resolution. Information on water demand, water availability and water stress at a monthly temporal resolution is essential for the planning of water reuse & recycling schemes, since both water demand and water availability vary throughout the year. For water demand this variability is most pronounced for water use in irrigated agriculture. For water availability the seasonality of rainfall and runoff determines the variability throughout the year. Information on the monthly variability water withdrawal for irrigated agriculture was only available for the Chilean study sites. For these sites, the PCRaster script has been adapted to allocate monthly proportions of the total irrigation water demand to the water user zones for irrigated agriculture (see Annex 1.9).

The lookup tables for the case study sites contain data on water use provided by the study site teams in the indicator database (AUA, 2013), from Deliverable 2.1 (Porto et al., 2012), from Deliverable 5.3, and from the literature. In case information on water withdrawal for urban zones was missing, the water withdrawal in each zone was determined based on the water use per inhabitant reported in the literature, the area of the zone and the population density in the zone. Both the water user zones maps and the lookup tables can be modified by the user to reflect different situations of water demand in the region of interest.

It should be noted that the water withdrawals mapped for use in an assessment of water scarcity as part of the final COROADO DSS are gross water withdrawals. This implies that the figures on water withdrawal do not reflect return flows of water that is not consumed for an intended purpose. There were several reasons for not incorporating return flows in a spatially and temporally distributed form in the WP4-tools for water demand assessment in the project:

1. Information on locations of return flows to the water systems was missing for several water use applications in the study sites. Return flows can be located at point locations or can be diffuse, as for example in the City of Cordóba, where the wastewater from buildings and industries not collected by the sewerage system (ca 50%) is returned to the basin by percolation to the groundwater, or by unknown discharge routes (Santiago Reyna, pers. comm.).
2. The spatial resolution of the PCRGLOBWB model and water demand and water stress assessment tools ($1*1\ km^2$) is too coarse for detailed water flow accounting. For example, in the case study site of SPMR, water supply to and return flows from water user units take place at locations at smaller distances.
3. Quantifying actual consumed water quantities, recoverable and non-recoverable return flows requires information on return flows in the case study areas at a monthly timescale. This information was not available. Some information on return flows (without indication of temporal scales, and without characterization of recoverable or non-recoverable nature) was collected from expert knowledge in the study site teams during the plenary project meetings, or could be inferred from simulations with the hydrological model (for agricultural use).

3.3 Application of the Water Demand Assessment Tool: example for the Mexican case study site

Figure 3 show the maps of water user zones for the case study site in Mexico. In the map of water user zones for urban/domestic use (a), the cities of Reynosa, Rio Bravo, Matamoros and Valle Hermoso have unique identifiers in the map (resp. 3, 4, 6 and 7) (Figure 3a). In the map of water user zones for industrial use (b), each industry has a unique identifier. In the map of water user zones for agricultural use (irrigation) (c), each subzone in the irrigation districts DR025 and DR026 has a unique identifier. The Water Demand Assessment Tool was developed using maps of water user zones in the current situation in the COROADO study sites, but maps with changed zones or new zones can be entered into the system. The identifiers should always refer to the identifiers used in the lookup tables. The numbers on water withdrawal or demand for each zone can be edited directly in the lookup tables.

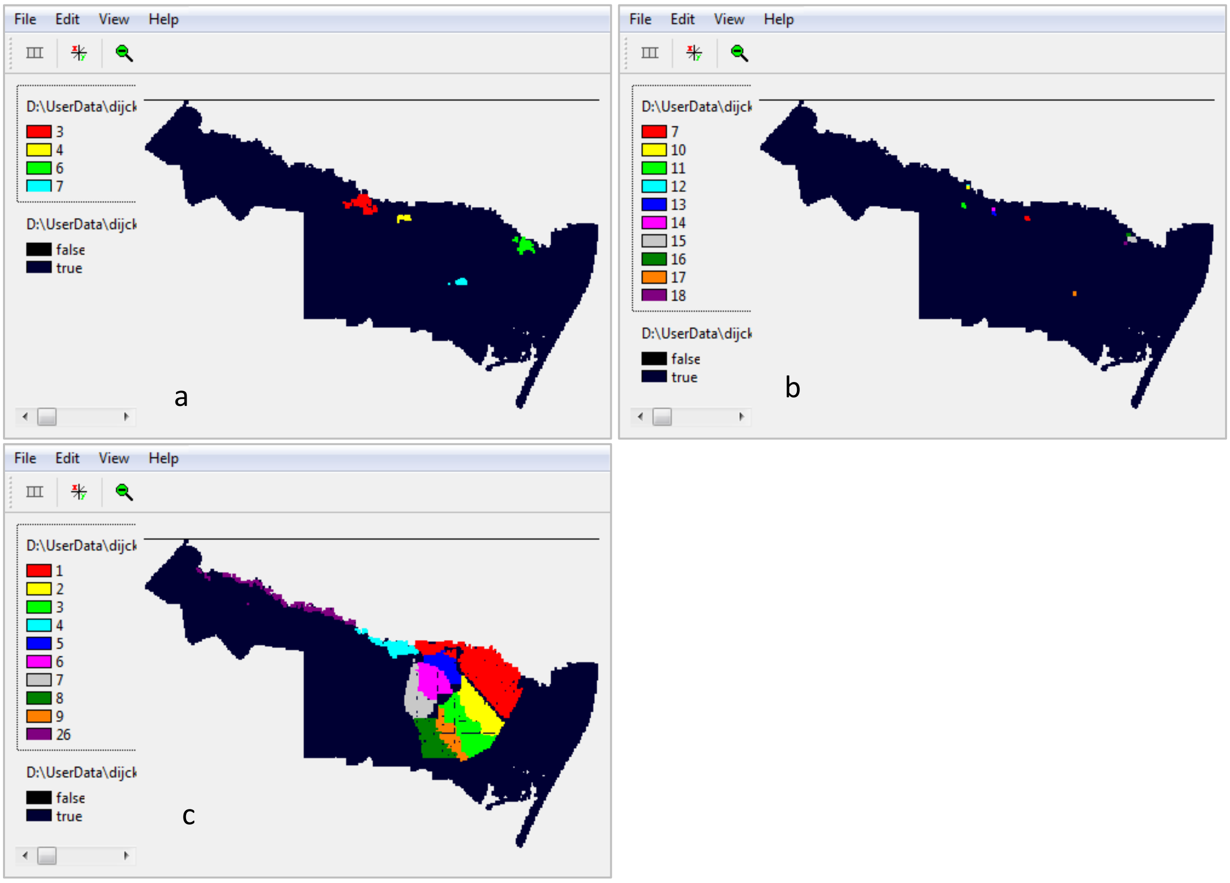

Figure 3 Water user zones for urban/domestic use (a), industrial use (b) and agricultural use (c) in the Mexican case study site.

The Water Demand Assessment tool assigns values of the gross annual water demand (in $m^3.s^{-1}$) to each water user zone in the maps of zones for urban/domestic use, industrial and agricultural use through the lookup tables for each water use type. For each water use type, a table for water withdrawal from surface water and from groundwater is available. Examples for the withdrawal of water for agricultural use in the Mexican case study site are shown in Figure 4. The numbers in the second column are the identifiers of the water user zones for agricultural use on the map in Figure 3c. The tables show that water for irrigated agriculture is withdrawn from the surface water only, and that the withdrawal is largest for zone 1.

waterdemand_surfwat_sectors_agr.tbl

1	1	6.54
2	2	3.61
3	3	4.06
4	4	0.73
5	5	1.70
6	6	3.08
7	7	2.90
8	8	2.71
9	9	1.95
10	26	1.3

waterdemand_groundwat_sectors_agr.tbl

1	1	0
2	2	0
3	3	0
4	4	0
5	5	0
6	6	0
7	7	0
8	8	0
9	9	0
10	26	0

Figure 4 Lookup tables of water withdrawal for agricultural use in the Mexican case study sites. Numbers in the second column refer to the water user zones on the map in

Figure 5 shows the maps resulting from the lookup operation of water withdrawal data from the lookup tables, and the allocation to the water user zones in the Water Demand Assessment Tool. The water withdrawal for urban/domestic and industrial use is mapped on an annual basis, and downscaled to months by assuming an equal demand in each month. The withdrawal for irrigation is mapped on a monthly basis, assuming an equal demand in each month of the growing season, or a share of the total irrigation demand based on a known distribution over the season (as in the Chilean study site). The PCRaster script sums the water withdrawals for the economic sectors to obtain a map of the total water demand in the region per month and per year (Figure 6). The maps of the water demand clearly show the dominant claim of the agricultural sector on water in the region, and also give insight in the variation of the total demand through the year.

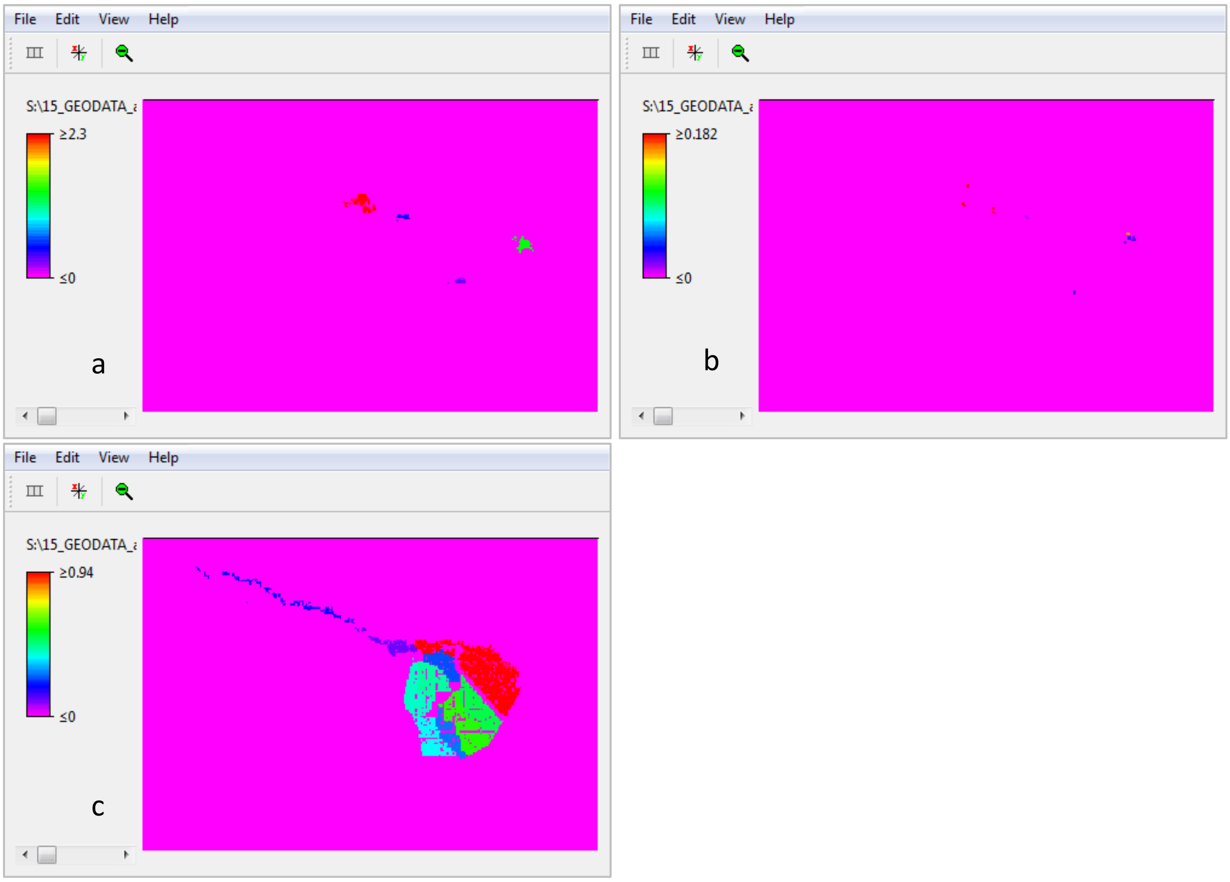

Figure 5 Water demand ($m^3.s^{-1}$) for urban/domestic (a), industrial (b) and agricultural use (c) in the Mexican case study site. Water demand for urban/domestic and industrial use is expressed on annual basis, water demand for agricultural use is the mean monthly demand in the growing season.

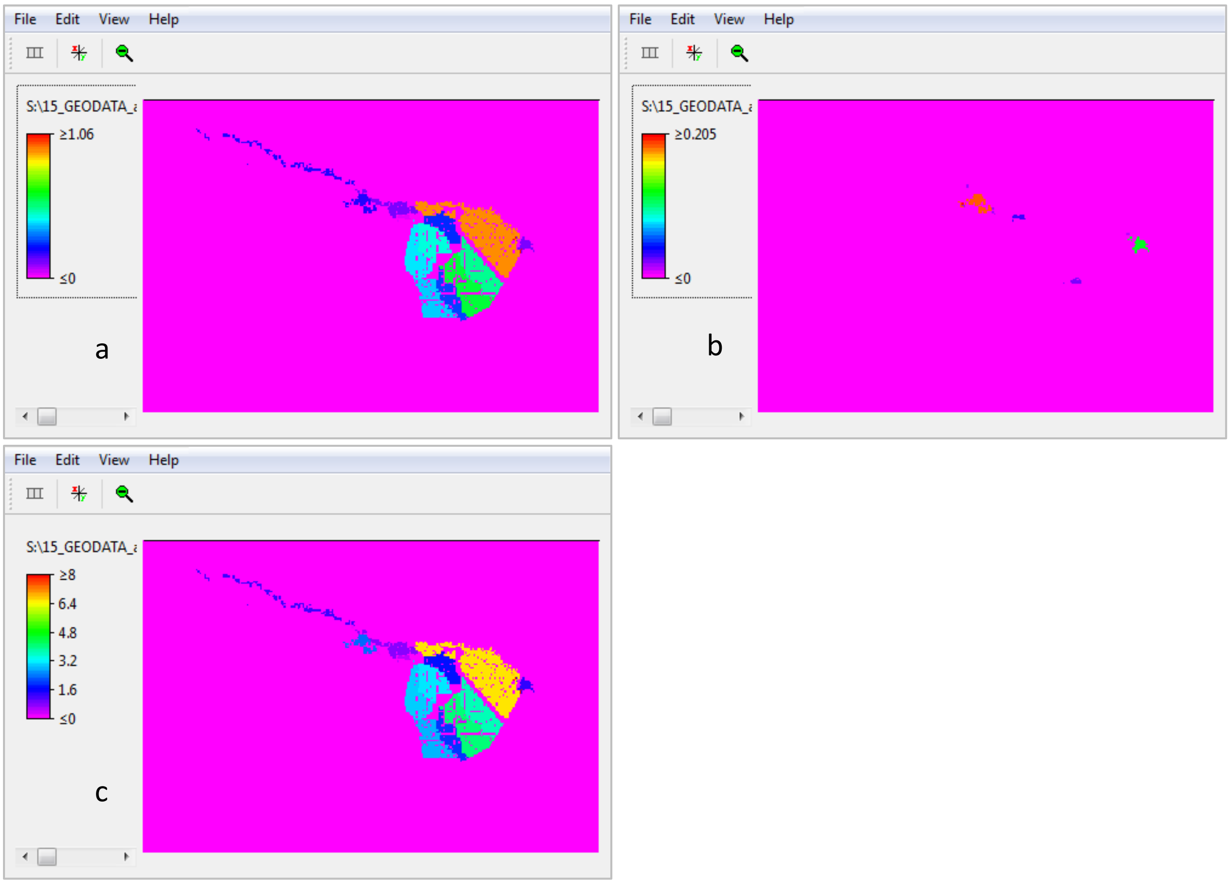

Figure 6 Total water demand ($m^3.s^{-1}$) for urban/domestic use, industrial use and agricultural use in the Mexican case study site in the months January (a) and September (b), and on annual basis (c).

3.4 References

Biemans, H. (Wageningen U. (2012). *Water constraints on future food production*. Wageningen University, WUR. Retrieved from http://edepot.wur.nl/233287

De Gruijter, J., Brus, D., Knotters, M., & Bierkens, M. F. P. (2005). *Sampling for Natural Resource Monitoring* (p. 352). Mairdumont Gmbh & Co. Kg.

Frederiksen, H. D. (2011). A common basis for analysis, evaluation and comparison of off-stream water uses. *Water International*, *36*(3), 266–282.

Gleeson, T., Wada, Y., Bierkens, M. F. P., & van Beek, L. P. H. (2012). Water balance of global aquifers revealed by groundwater footprint. *Nature*, *488*(7410), 197–200. doi:10.1038/nature11295

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. (n.d.). *The Water Footprint Assessment Manual*.

Vorosmarty, C. J. (2000). Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science*, *289*(5477), 284–288. doi:10.1126/science.289.5477.284

Wada, Y., van Beek, L. P. H., & Bierkens, M. F. P. (2011). Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability. *Hydrology and Earth System Sciences*, *15*(12), 3785–3808. doi:10.5194/hess-15-3785-2011

Wada, Y., van Beek, L. P. H., Viviroli, D., Dürr, H. H., Weingartner, R., & Bierkens, M. F. P. (2011a). Global monthly water stress: 2. Water demand and severity of water stress. *Water Resources Research*, *47*(7), n/a–n/a. doi:10.1029/2010WR009792

Wada, Y., van Beek, L. P. H., Viviroli, D., Dürr, H. H., Weingartner, R., & Bierkens, M. F. P. (2011b). Global monthly water stress: 2. Water demand and severity of water stress. *Water Resources Research*, *47*(7), n/a–n/a. doi:10.1029/2010WR009792

Yang, H., Pfister, S., & Bhaduri, A. (2013). Accounting for a scarce resource: virtual water and water footprint in the global water system. *Current Opinion in Environmental Sustainability*, *5*(6), 599–606. doi:10.1016/j.cosust.2013.10.003

4 Water Stress Assessment (Module 3)

4.1 Introduction and method

The concept of water stress is used in the WP4-tool for the objective to 'highlight areas at risk regarding water scarcity and water quality under current and future conditions' (chapter 1). Many definitions of 'water stress' are used in the literature on water scarcity (e.g. (Perveen & James, 2010), (Bär & Lehmann, 2012), (Brown, Matlock, & Ph, 2011). Most definitions combine elements of water quantity and quality in relation to water demand, since water stress can be caused both by insufficient water at the requested time and place, and by water of insufficient quality for applications of interest (Yu, 2013). Solutions in wastewater treatment and recycling technologies should address both aspects (Wintgens & Hochstrat, 2006), (US-EPA, 2012), (UN, 2013) (chapter 6).

We searched the literature for existing indices of water scarcity and water stress, that would be suitable for the purpose of the WP4-tool to highlight areas at risk of water scarcity and quality under current and future conditions. Many of the indices were found not suitable, because they describe water scarcity at larger spatial and temporal resolutions than required to show differences within regions of the size of the case study regions (8000-20.000 km^2), and to show variations within the year (e.g. (Brown et al., 2011)). For example, the Falkenmark Indicator (Falkenmark & Lindh, 1976) describes the fraction of total annual runoff available for human use at the level of countries. The Water Resources Vulnerability Index (Raskin et al., 1997) is also defined at the level of countries, as the ratio of total annual withdrawals to available water resources (WTA ratio). This index is commonly used in water resources analyses in combination with the "criticality ratio"—the ratio of water withdrawals for human use to total renewable water resources (Alcamo, Henrichs, & Rösch, 2000).

The WP4-tool used a spatially distributed index of water stress based on aspects of water quantity and water quality similar to the WTA ratio, capable of providing information at a monthly temporal resolution, and capable to integrate climate forcing under current and future conditions. This water stress index (WSI) is defined by comparing blue water availability with corresponding net total blue water demand following the definition also used in the global water stress assessment using the PCRGLOBWB model (Y. Wada, van Beek, & Bierkens, 2011), (Yoshihide Wada et al., 2011), and (van Beek, Wada, & Bierkens, 2011). The index is similar to the geospatial Index of Local Relative Water Use by (Vorosmarty, Douglas, Green, & Revenga, 2005) in that it compares the summed domestic, industrial and agricultural water use (in volume per time unit) to the locally generated discharge including discharge from upstream cells. The WSI is represented at a spatial resolution of 30 arcseconds (ca 1 km), compared to the grid cell size of 8-10 km used in the indices from (Y. Wada et al., 2011) and (Vorosmarty et al., 2005).

Differences from the presented Water Stress Index for the COROADO WP4-tool with the indices from the literature mentioned in the above are:

- Due to the smaller spatial resolution, the WSI is suitable to consider the spatially explicit location of water user units in a river basin, and can therefore be used to identify zones of water stress within the basin in more detail;
- The WSI takes account of the distance of water user units in the region from actual points of water supply, including groundwater wells, instead of considering only rivers and locally available groundwater as sources of renewable water supply;
- Since the WSI is based on generic characteristics of water systems (local relative water demand and distance from water supply points), it can be used to compare water stress conditions between river basins;
- The WSI considers water supply and water use on a monthly timescale, and can therefore be used to capture seasonal phase shifts in peak water demand and water availability, and to assess frequency and persistence of water stress;
- The WSI can take into account other types of friction to the supply from water source to water user, like differences in elevation and differences in water quality.

The WP4-tool is programmed as a cartographic modelling script in the PCRaster Package (http://pcraster.geo.uu.nl/pcraster/4.0.0/doc/manual/secintro.html) (see chapter 3 Water demand for explanations on PCRaster). The full script is included in Annex 1.9 to this report. It includes the Water Demand Assessment Tool described in chapter 3.2.
The WSI is based on the relative water demand by water users on a given location in the region (the local relative water demand), and a 'friction-distance' function, that expresses the friction that should be overcome in order to supply available blue water from points of extraction to the locations of water users (Figure 1). The points of extraction or water supply points can be groundwater pumping wells, intake points from rivers and reservoirs, or series of grid cells representing canals with multiple inlets (e.g. Figure 2). An example map of water supply points for the case study area in Mexico is shown in Figure 3 and Figure 4.

The friction-distance is calculated as the cumulative friction over the shortest 'friction path' from the water supply point to the water user (Figure 1). The friction on the supply of available blue water from water supply points to users can be imposed by different factors. Examples are listed in Table 1, together with the spatial variables used to calculate the 'friction-distance' from water supply point to water user. The aim of WP4 was to provide the Water Stress Assessment tool with default friction-distance functions for distance and water quality (Table 1). However, there was insufficient information on the actual status of water quality in the study areas to create maps of actual water quality in the freshwater and groundwater bodies. For this reason, the default function implemented in the WP4-tool is the friction-distance function based on the distance from the location of water extraction to the locations of water users. A provisory friction-distance function for water quality was programmed for the case study site of São Paulo, based on water quality standards of the surface water bodies, instead of spatial information of the actual water quality. The other friction-distance functions can be programmed in the tool provided that maps of the spatial variables in Table 1 are available and defined in the cartographic modelling script.

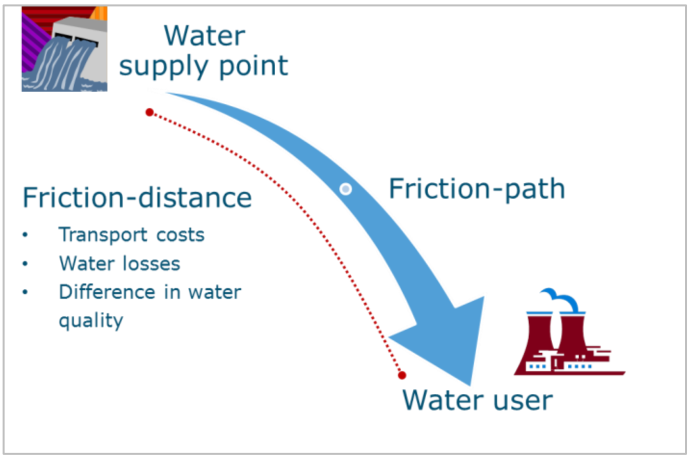

Figure 1 Concept of friction in the WP4-tool causing water stress at the locations of water users.

Table 1 Factors imposing friction to water supply from points of extraction to water users

Friction factor	Specification	Spatial variable for friction-distance calculation
Transport costs	Energy (pumping) Infrastructure Physical suitability	Distance water supply point-user Slope gradient Inaccessible zones for transport pathways for physical reasons
Accessibility	Availability of existing infrastructure (pipes, canals, storage facilities) Required deviations above- or underground (e.g. for protected areas, residential areas, property rights)	Available infrastructure Inaccessible zones for transport pathways for institutional reasons
Water losses	Leakages Spill-overs Informal intakes	Locations of leakage, spill-over, informal intakes
Water quality	Effort required to upgrade water quality from water at supply points to quality required by the user (A-C)*	Actual water quality status at water supply points

[a] see Chapter 6 ‘ Evaluation of water treatment options’

Figure 2 Water supply point: intake point from the Los Molinos Channel, Cordóba Province, Argentina. Photo: Celia Martins-Bento.

The water scarcity index WSI is calculated for each grid cell in the region of interest as:

$$WSI_{m,s}^{i} = \log\left(FRICDIST^{i} \cdot D\_WA_{m,s}^{i} + 1\right)$$

Equation 1

$WSI^{i}_{m,s}$: water scarcity index in grid cell i in month m and scenario s
FRICDIST: cumulated friction-distance over the shortest friction-path from water supply point to cell i (number of cells)

$D\_WA^{i}_{m,s}$: relative water demand[1] of all water uses in grid cell in month m ($m^3.s^{-1}$)

The 'p+1' variant of the log10 transformation is used to prevent a zero basis for the log-function, in case the relative water demand is zero. Scenario s refers to the time window used for the water stress assessment: either the baseline situation of 2000-2010, or the 5 scenarios of future climatic change, projected in the period 2040-2050. The friction-distance (FRICDIST) is calculated using the hydrological analysis function ' **spread()**' from the PCRaster Package. This function reads:

FRICDIST = **spread(**watersupplypoints, initialfriction, friction);

Equation 2

watersupplypoints: a map of water supply points (e.g. Figure 3)
initialfriction: map of initial friction-distance at water supply points
friction: map of friction accumulated when moving in the area from the water supply point to water user unit

During spreading a path is followed over the consecutive neighbouring cells, starting at the grid cells representing the water supply points (e.g. Figure 3) to any location in the region of interest. While following this path, the friction-distance increases. The increase of friction-distance per unit distance is specified by the cell values on a map representing the variable causing friction (Table 1). Using these values, the increase when travelling from one cell to its neighbouring cell is calculated as follows. Let friction(source cell) and friction(destination cell) be the friction values at the cell where is moved from and where is moved to, respectively. While moving from the source cell to the destination cell the increase of friction- distance is:

$$\Delta(fricdist) = d \cdot \frac{[fric(sc) + fric(dc)]}{2}$$

Equation 3

Δ(fricdist): increase of friction-distance per unit distance
d: distance between the source cell and the destination cell (in number of cells or true distance along the friction path)
fric(sc): friction value at the source cell
fric(dc): friction value at the destination cell

The distance between the source cell and the destination cell equals the cell length if the source cell and the destination cell are neighbours in horizontal or vertical directions. It equals $\sqrt{2}$ multiplied by the cell length if the cells are neighbours in diagonal directions.

FRICDIST calculated with Equation 2 then gives a map with an expression of the friction that is encountered in a water system on the allocation of water from defined sources where blue water is available to locations of water users in need of water in the river basin under consideration. For the default friction-distance function based on distance, the initial friction-distance at water supply points in Equation 2 is set to zero, since the distance from these points is zero at these locations. The map of friction on the way from water supply point to water user is set to values of 1 in all cells, since the cells are of equal size. The friction-distance is then expressed as the cumulative number of cells that must be crossed to transport water from supply points to any location in the region of interest. The maps of friction-distance that are calculated when running the water stress assessment tool for the four case study sites are shown in Figure 5.

[1] Water demand is approximated by actual withdrawal in the WP4-tool, for reasons explained in chapter 3 Water demand assessment.

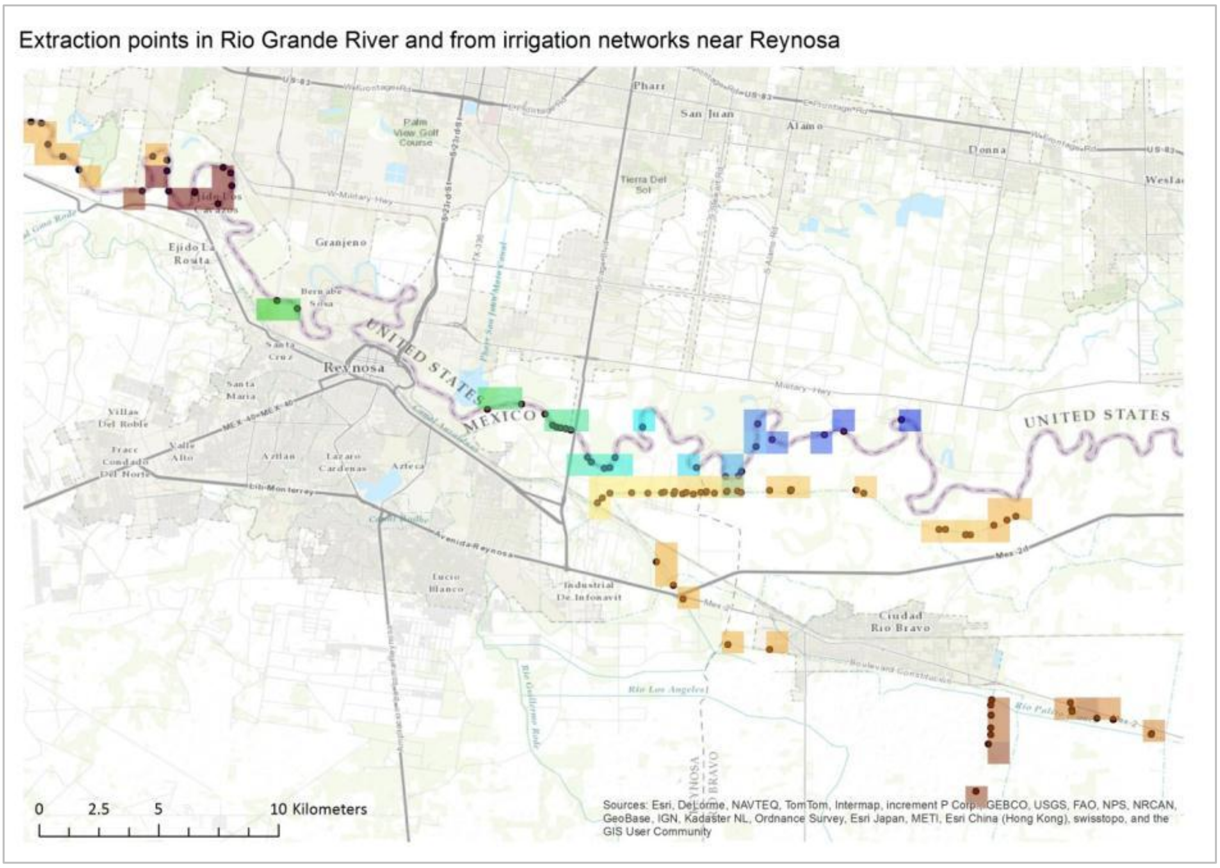

Figure 3 Grid cells representing water supply points in the case study site in Mexico. The dots are the locations of intake points from the Rio Grande River and the Anzalduas irrigation canal. Source data point locations: Tecnología de Calidad, S.A. de C.V., Mexico.

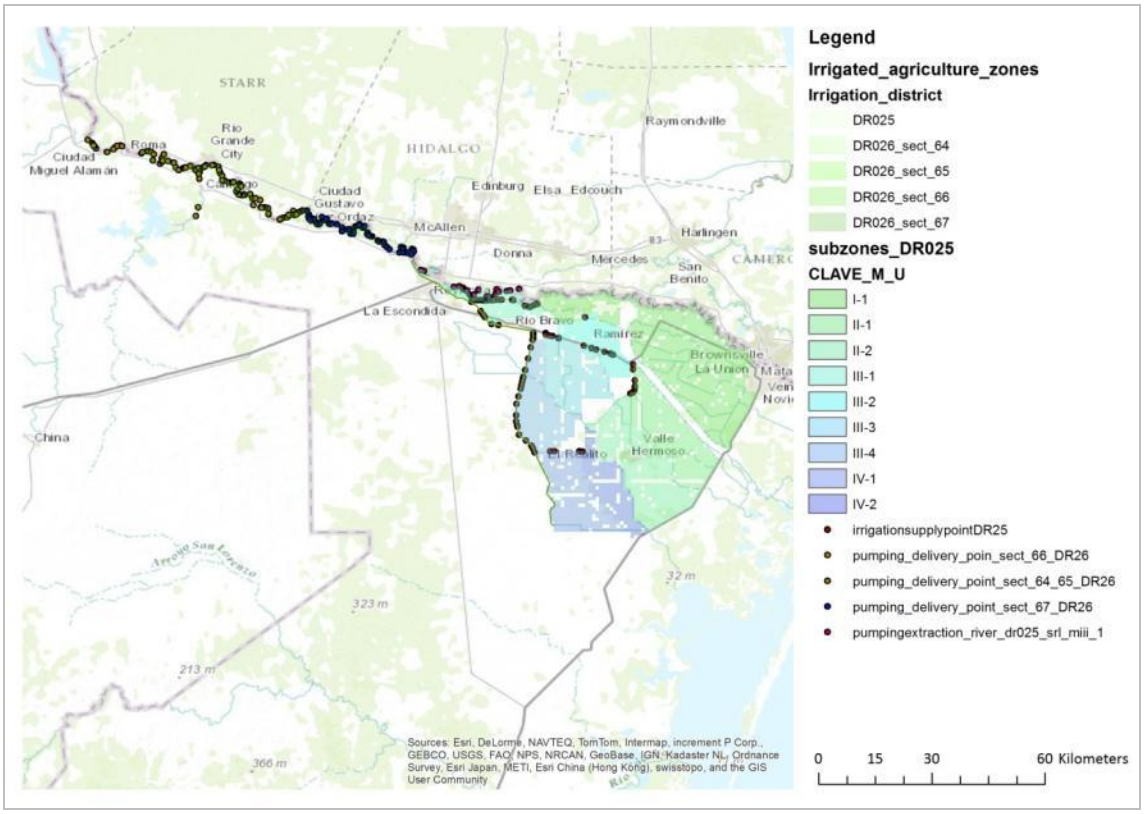

Figure 4 Water supply points for irrigation in the Mexican case study site. Source data point locations: Tecnología de Calidad, S.A. de C.V., Mexico.

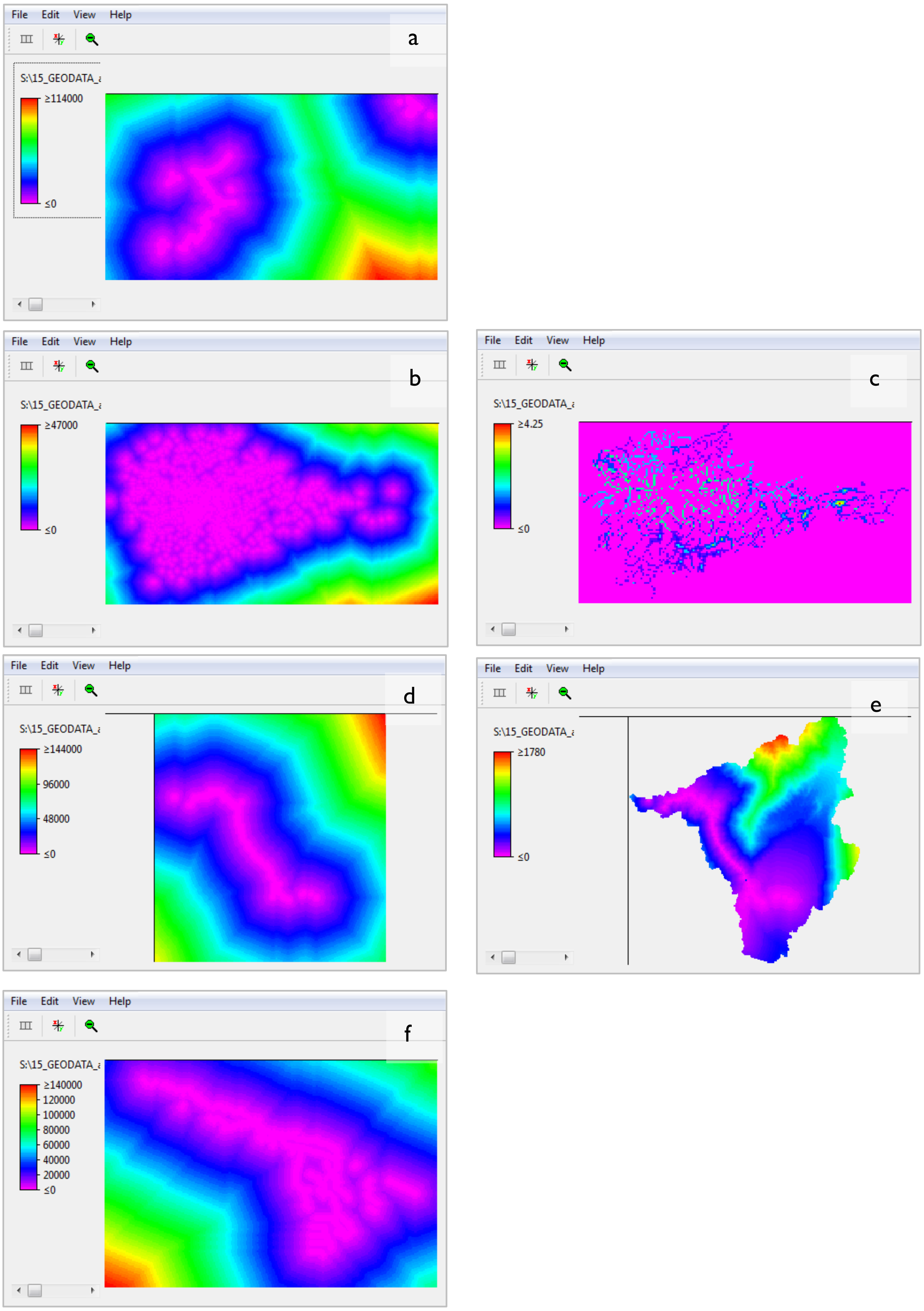

Figure 5 Friction-distance (expressed as the number of cumulated cells) on the path from water supply points in case study areas. a: Suquía River Basin, Argentina; b and c: Alto Tiête River Basin, Brazil, d, e: Copiapó River Basin, Chile; f: Lower Rio Grande River Basin, Mexico. c represents friction-distance based on difference in water quality in surface waters; e represents friction-distance based on the storage volume in the groundwater.

The maps of friction-distance in Figure 5 show that close to the water supply points, the friction-distance is low (purple colours), and that it increases with distance from the supply points to locations further away in the regions (green, yellow and red colours). The friction-distance map based on the legal water standard for surface bodies in the case study area in Brazil (figure c) was calculated from water quality standards for fresh water bodies in the legislation CONAMA 20/1986 (Aronne & Jacomino, 2002). These standards distinguish 4 water quality classes, ranging from 1 (domestic use with pre-treatment, environmental protection, recreation, fish breeding and irrigation of crops eaten raw) to 4 (navigation, scenery ornament and less demanding uses). In the calculation of friction-distance from the water supply points to any location in the river basin, the value of the legal water quality standard is accumulated on the path. Water supply paths crossing cells in surface water bodies with a low legal water quality standard (3, 4) will result in larger values of the friction-distance at a given location in the river basin than water supply paths crossing the same number of cells with a higher legal water quality standard (1,2). This calculation reflects that a larger friction is imposed on the water supply by bringing water with a lower legal quality standard to a water user, than bringing water with a higher legal quality standard, due to the associated costs for water treatment. Of course the legal water quality standard does not reflect the actual water quality of surface water bodies. As mentioned previously, the information on the quality of fresh water bodies in the case study areas was too sparse to develop friction-distance maps based reflecting limitations on water supply due to insufficient water quality.

The friction-distance map based on the storage volume in the groundwater for the case study area in Chile (figure e) was calculated from the average annual storage in the groundwater store over the period 2000-2010, as calculated from the PCRGLOBWB model. The different calculation base of this type of friction distance shows from the varying rates of increase in the friction-distance from water supply points to other locations in the catchment: the increase is more gradual in the southern parts of the path along the axis of the main river, because the groundwater body covers a larger area here.

Reverting to Equation 1, the local relative water demand is defined as (Equation 4):

$$D\_WA^i{}_{m,s} = D\_TOT^i{}_m / qavg^i{}_{m,s}$$
$$qavg^i{}_{m,s} > 0$$

Equation 4

where:

> $D\_WA^i{}_{m,s}$: local relative water demand[2] of all water uses in grid cell i in month m ($m^3.s^{-1}$) and scenario s
> $D\_TOT^i{}_m$: total water demand[3] in grid cell i for all water uses in month m ($m^3.s^{-1}$)
> $qavg^i{}_{m,s}$: potential available blue water in grid cell i in month m, averaged over 10 years in the baseline situation (2000-2010) (s) or under a future climate change scenario (2040-2050) (s)

The total water demand in a grid cell ($D\_TOT^i{}_m$) includes the water withdrawal recorded for all water uses in that cell in the tables of water withdrawal related to the maps of water user zones, as resulting from the application of the Water Demand Assessment Tool explained in Chapter 3. The water uses include use for urban and domestic purposes, industry, mines and agriculture. Environmental water requirements were considered for the case study area in Argentina, for which a minimum required river flow was provided.

The potential available blue water $qavg^i{}_{m,s}$ is obtained from the assessment of potential available blue water using the PCRGLOBWB model, as documented in chapter 2 (Module 1). Model outputs for the baseline condition (2000-2010) were used, as well as outputs for the 5 climatic scenario's described in chapter 2.5 . For each month, the aggregated value of the minimum, mean and maximum potential available blue water was used over the 10-year period representing the baseline period (2000-2010) and a 10-year period centred around 2050 for the climate scenario's.

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[2] Approximated by actual withdrawal in the WP4-tool, for reasons explained in chapter 3 Water demand assessment.
[3] Approximated by actual withdrawal in the WP4-tool, for reasons explained in chapter 3 Water demand assessment.

The water demand is expressed on a monthly basis, corresponding to the temporal resolution of the information on water withdrawal for irrigated agriculture (see chapter 3) and on potential blue water availability, resulting from the PCRGLOBWB model (see chapter 2). However, the primary information on water withdrawal used to parameterise the water demand for urban/domestic use, industrial use and mining was available on an annual basis only, and was converted to monthly values in the tool by assuming an equal demand in each month. Consequently, the monthly variation of the water stress index calculated using Equation 1 is due to the monthly variation of the potential blue water availability and the water demand for irrigated agriculture. The cartographic modelling script can be adapted in future projects to employ monthly values of observed or modelled water withdrawal or demand, should these become available.

4.2 Application to the case study areas

All steps in the application of the modules for water demand assessment (module 2, see chapter 3) and water stress assessment (module 3) in the WP4-tool are illustrated for the case study area in Argentina below. Next, the results of the application to all four case study areas are discussed. All results are documented as HTML-files, displayed in Annex 1.10. of this report, and provided to the COROADO DSS.

4.2.1 Example application to the case study area in Argentina

Water demand assessment

The gross blue water demand for the case study area in Argentina under baseline conditions (2000-2010) was approximated from the gross water withdrawal from surface and groundwater for different settlement zones (Figure 6). The approximation was based on the total withdrawal reported for urban and domestic use in the indicator database (AUA, 2013) and in the literature, and the number of inhabitants. Cordoba City was subdivided in 3 zones based on the literature. The water withdrawal in each zone was determined based on the water use per inhabitant reported in the literature, the area of the zone and the population density in the zone. For the urban settlements in the Suquía basin and Los Molinos river basin water withdrawal was allocated to zones based on a total of 1.5 m3.s-1 for the settlements in the Suquía River Basin, and 0.5 m3.s-1 in the Los Molinos basin (Porto et al., 2012; Del 2.1).

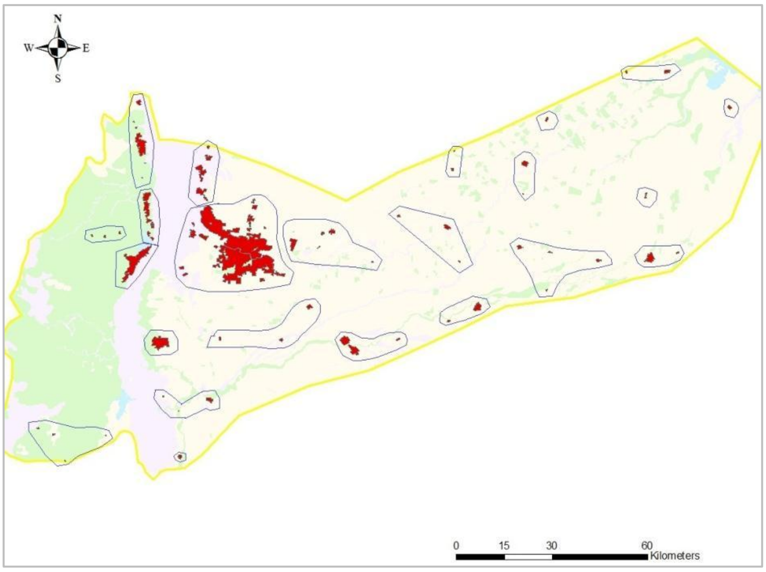


Figure 6 Delineation of urban zones for mapping gross water demand for urban/domestic use in Suquía River Basin.

Gross water withdrawal for agricultural use from surface and groundwater was derived from the total withdrawal reported for agricultural use in the indicator database (AUA, 2013), and divided over the northern and southern zone based on the irrigated area in each zone.

For environmental water demand, the University of Cordóba reported a minimum flow of 1 $m^3.s^{-1}$ at the location of Mal Paso Dike. The proportion of this value and the mean monthly available flow at Mal Paso

Dike was used to scale environmental flow requirements for other locations in the catchment. An example is shown in Figure 8. Based on this procedure, the environmental flow requirement is highest in downstream parts of the Suquía and Los Molinos rivers, and in the months with the lowest available water (i.e. the driest months, May to September).

Gross annual water withdrawal for the major water users in the Suquía River Basin is mapped in Figure 7. Withdrawal for urban and domestic appliances is largest, up till 3.8 $m^3.s^{-1}$ for Cordóba City, mainly withdrawn from surface water. Industry is the smallest user with 0.61 $m^3.s^{-1}$ by the Industrial Park of Cordóba. Of this amount, 0.03 $m^3.s^{-1}$ is reused and supplied by own wastewater recycling facilities of the industrial park. No information was available on water withdrawal by other industries.

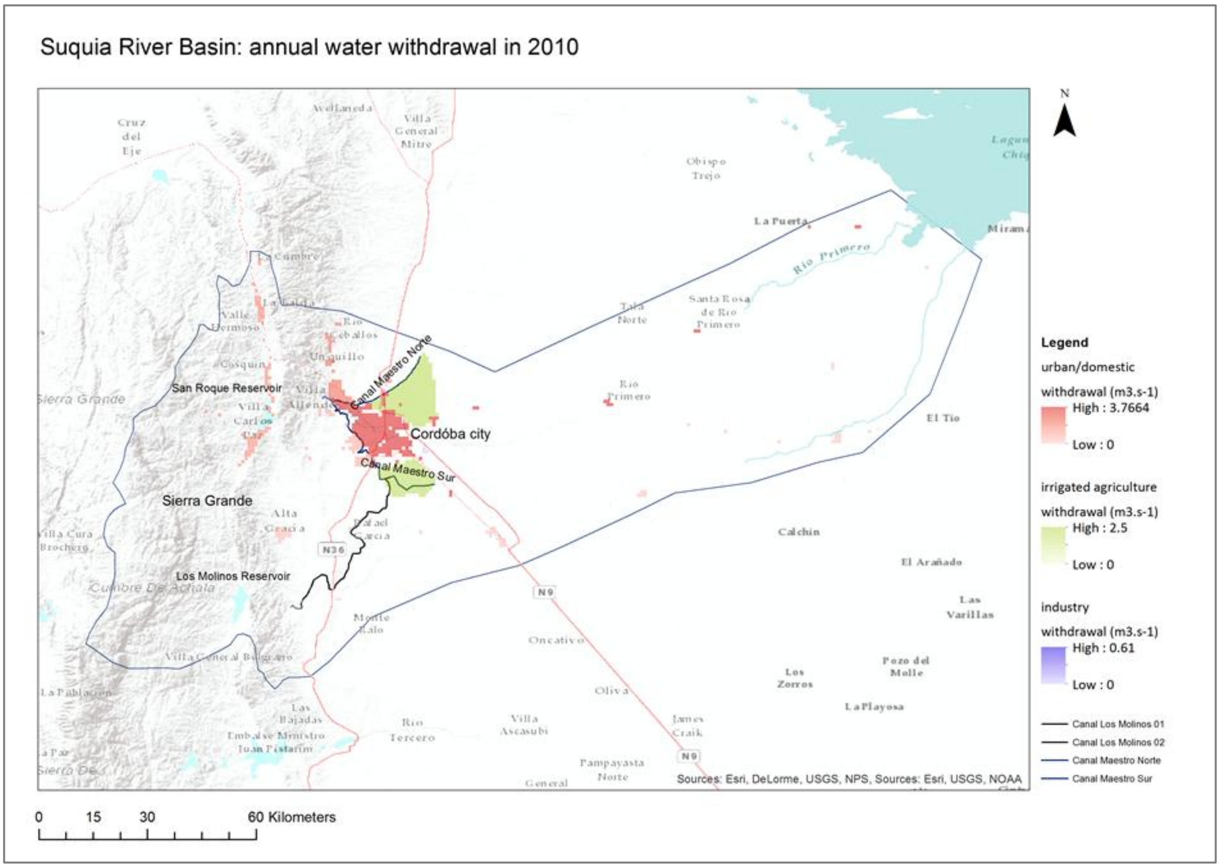


Figure 7 Annual water withdrawal by main water users in the Suquía River Basin in 2010. Source data: University of Cordóba, Argentina.

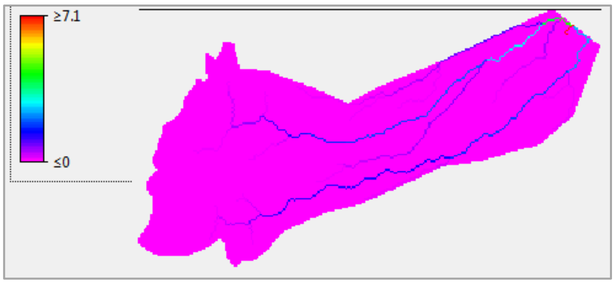


Figure 8 Mean environmental flow requirement for the Suquía River Basin in the month January (m3.s-1), extrapolated from data for the water supply point of Mal Paso Dike for the period 2000-2010.

Figure 9 shows maps of the summed gross blue water withdrawal for urban and domestic use, industrial use and irrigated agriculture in four months of the year, calculated by the Water Demand Assessment Tool (see chapter 3.2). The figures show the demand for irrigation water in the months January and October, and the constant demand[4] from the city of Cordóba in all months.

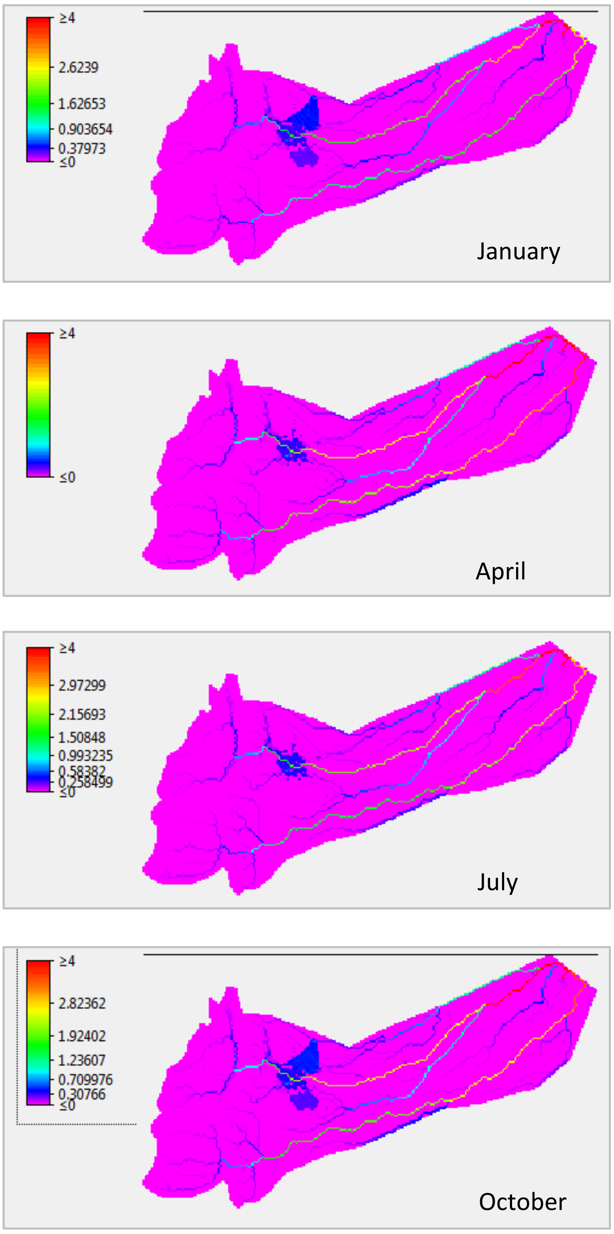


Figure 9 Maps of total gross blue water demand, approximated by actual withdrawal (in $m^3.s^{-1}$), in January, April, July and October of 2010 . Source data: Cordóba University.

Water stress mapping – Argentina case study area

Monthly maps of the Water Stress Index were calculated using the Water Stress Assessment Tool as explained in section 4.1. The maps of the water stress index for the case study area in Argentina are shown in Figure 11; the maps for the other case study areas are shown in Annex 1.10.

The maps show that the highest values of the WSI occur in urban settlements and in the irrigated areas, and the lowest values occur on the locations of water supply points or near these: the reservoirs of San Roque and Los Molinos and the Los Molinos channel (Figure 10).

[4] As mentioned in section 4.1, data on monthly water demand from observations or modelling can be entered into the Water Demand Assessment Tool to include monthly fluctuations in demand as an influencing factor for monthly variations in water stress conditions.

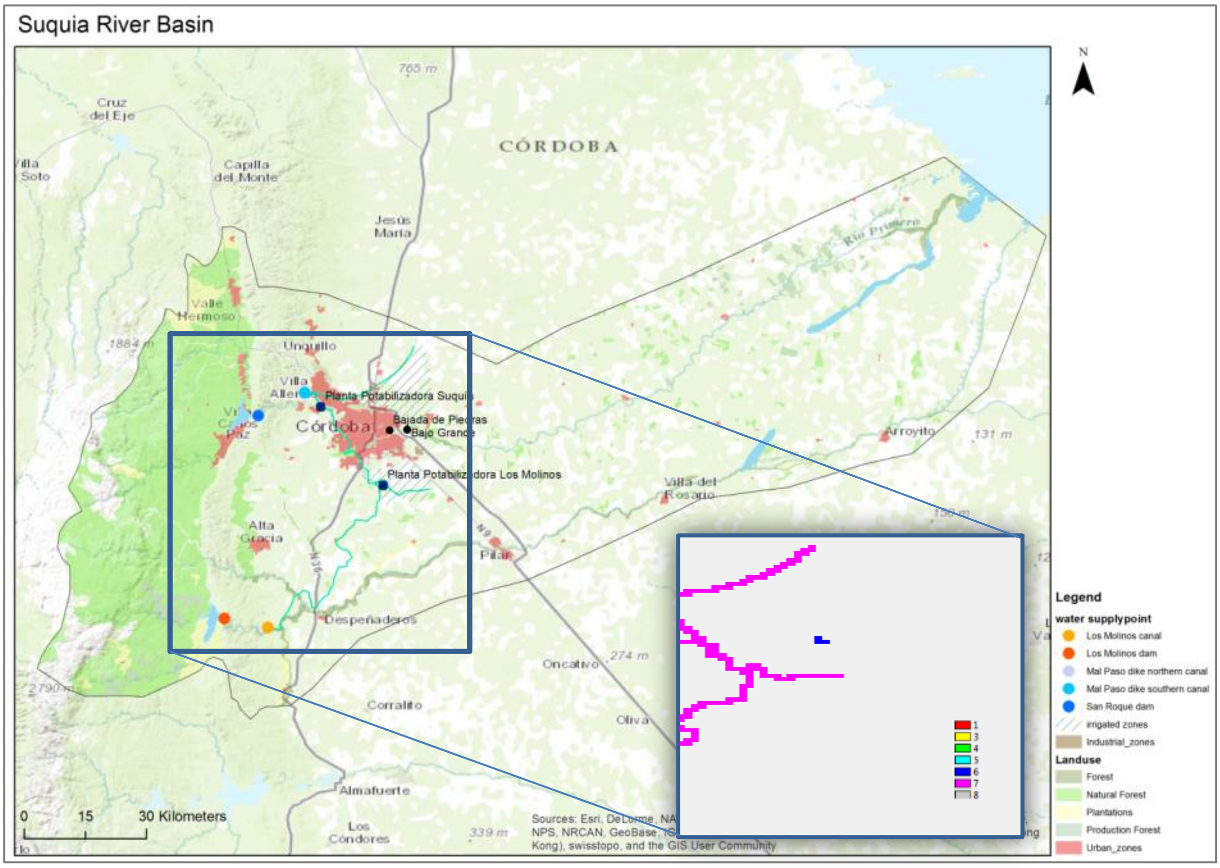
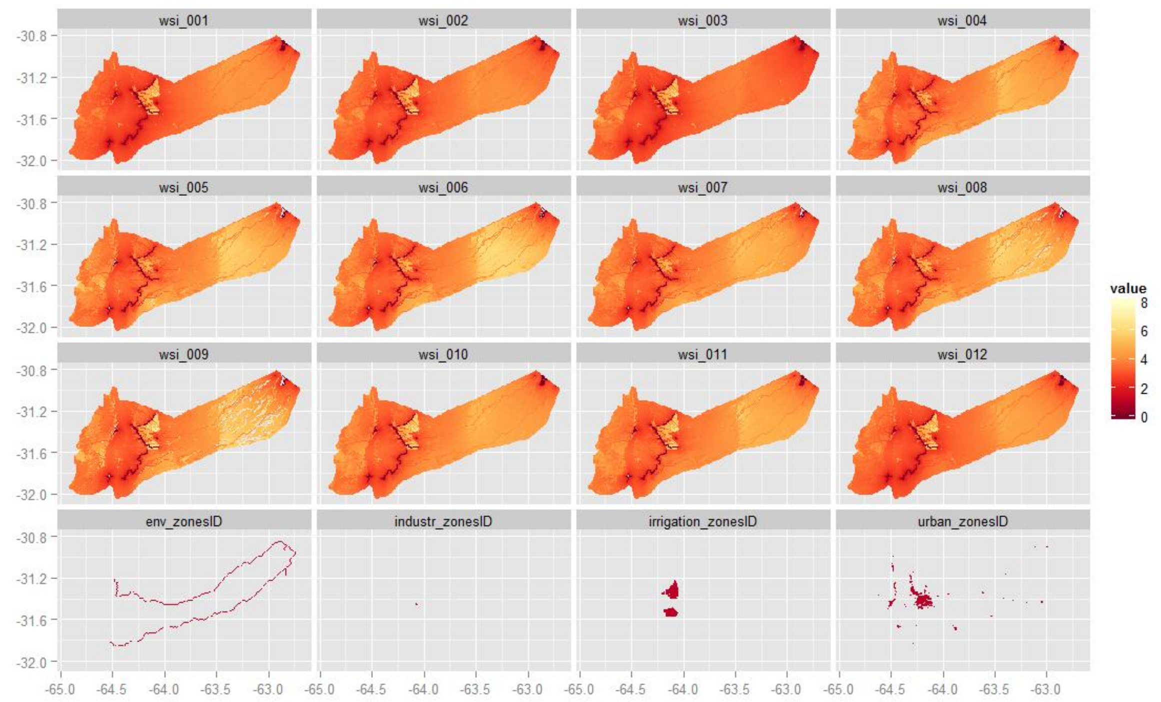


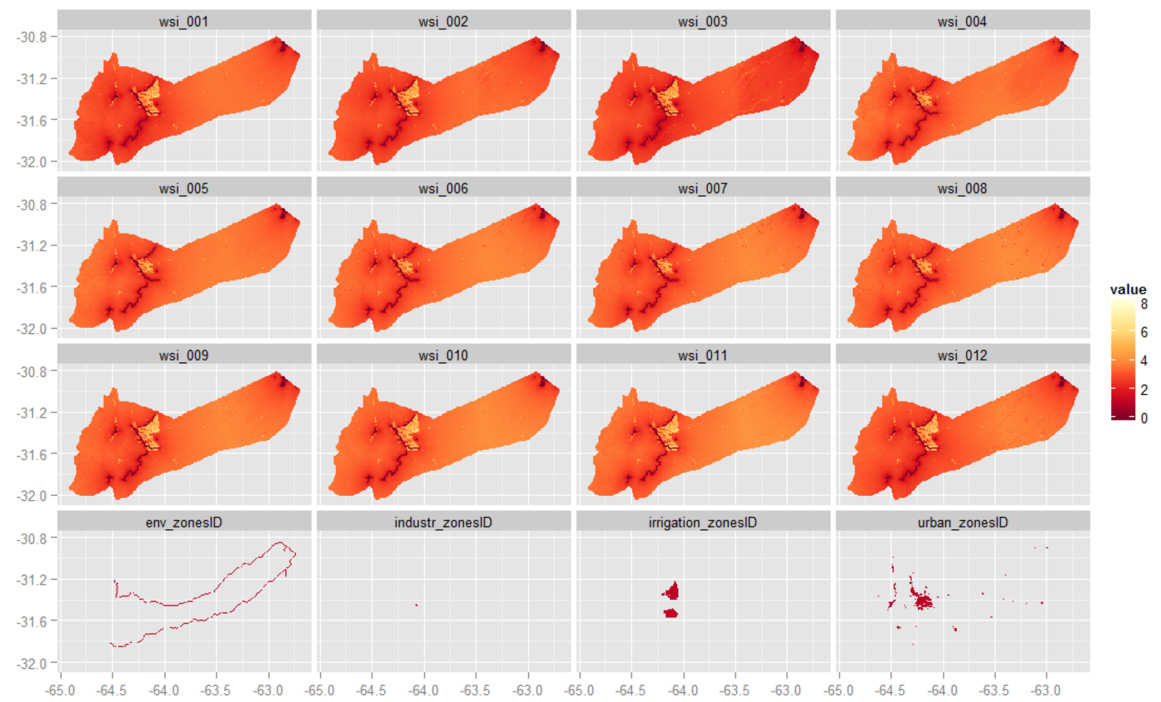
Figure 10 Water supply points in the Suquía River Basin configured in the WP4-tool. The rectangular inset shows the representation as a PCRaster input map for the WP4-tool. Numbers in the legend are unique identifiers for water supply point locations, reservoirs or channels.

The maps show that the area at risk of water scarcity (relatively high values of WSI, depicted in lighter orange colour) is largest in the months September to March, coinciding with the period of the year in which irrigation water is required for the agricultural areas north and south of Cordoba City. The highest values occur in the eastern part of the city and the irrigated zones, because these are most distant from the water supply points (Mal Paso Dike and the canals 'Maestro Norte' and 'Los Molinos 2'). Values are higher in the northern irrigated zone because the demand is larger in that zone (0.4 $m^3.s^{-1}$ for the month October, versus 0.2 $m^3.s^{-1}$ for the southern zone). In the remaining period of the year (April-August), there is no irrigation requirement, and the higher values of the WSI in the maps reflect water demand for urban and domestic use in Cordóba City and the other settlements in the area.

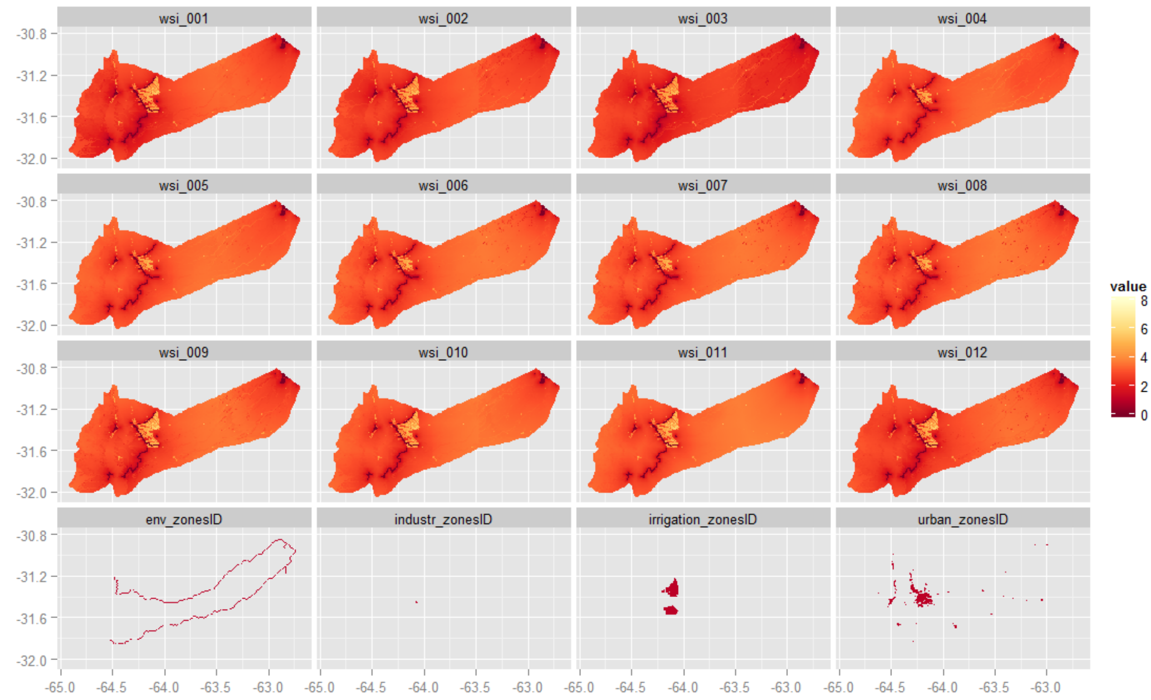
There is a clear influence of the variability in the potential available blue water per month, as simulated by the PCRGLOBWB model, on the level of the WSI and its spatial distribution, as can be seen by comparing the WSI maps for a given month between Figure 11 a, b and c. When the minimum potential available blue water flow is considered, the WSI is highest in a given month (lighter orange colours), and the spatial variability is also largest, particularly in the mountainous area in the western part of the river basin, that provides a large part of the surface and groundwater to the river basin, and in the downstream part of the river basin, that is located relatively far from blue water sources.



(a) WSI based on minimum potential blue water availability over 2000-2010

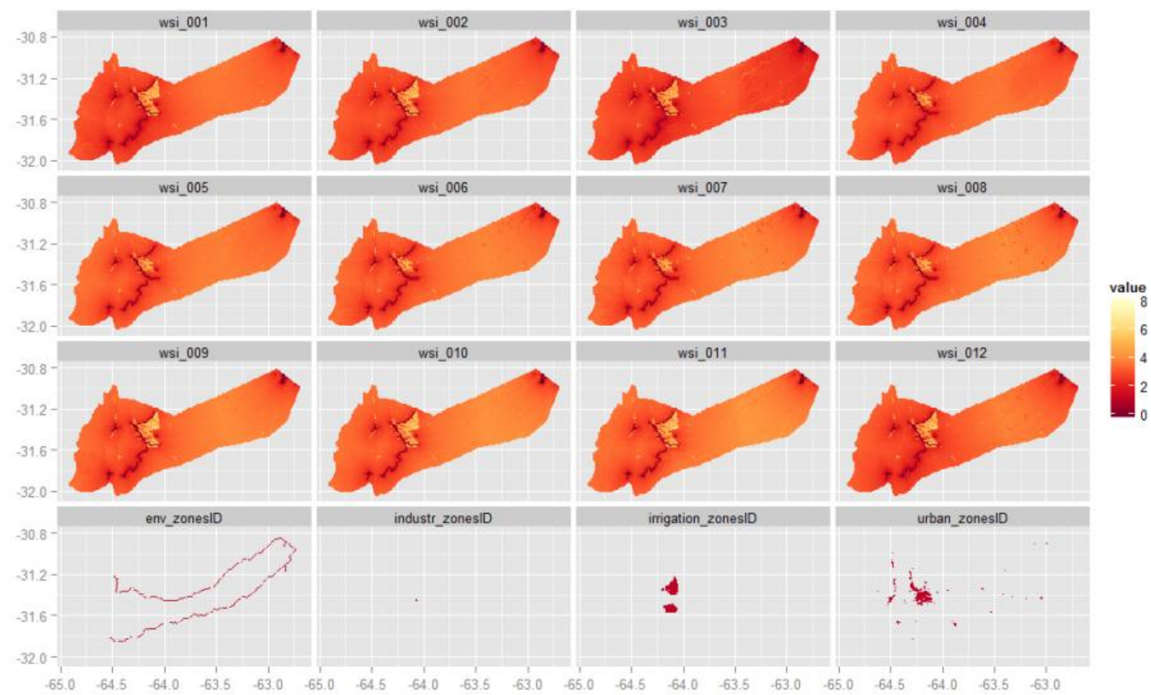


(b) WSI based on mean potential blue water availability over 2000-2010

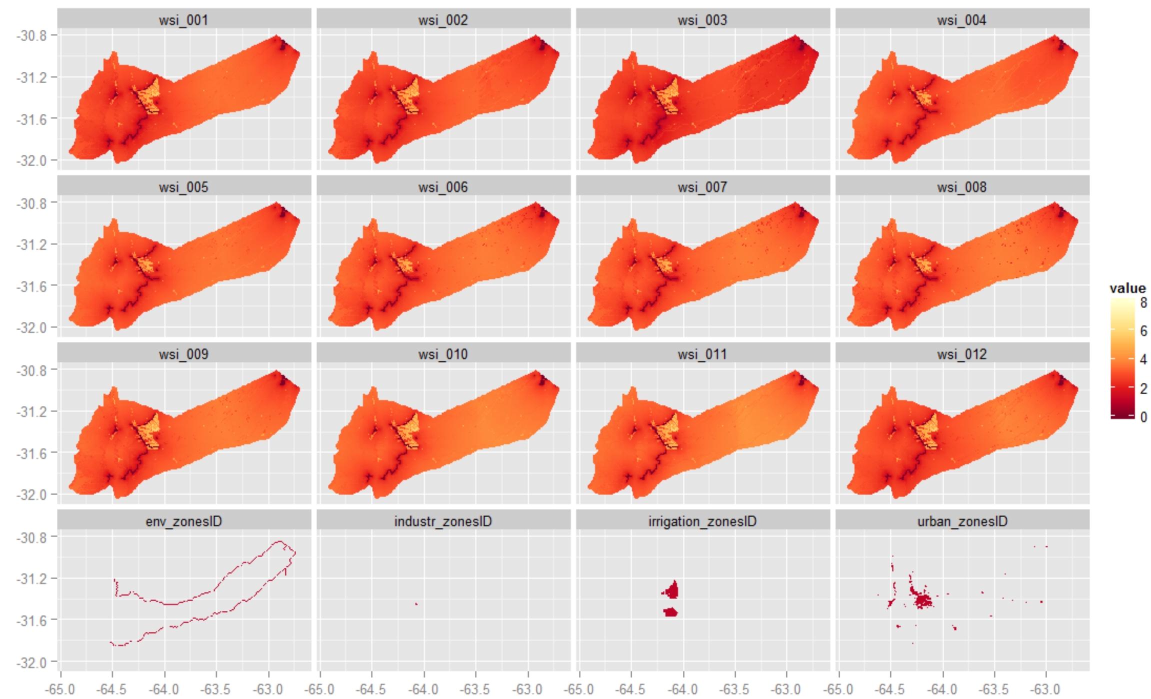


(c) WSI based on maximum potential blue water availability over 2000-2010

Figure 11 Monthly Water Stress Index (WSI) maps of Suquía River Basin, based on minimum (a), mean (b) and maximum (c) potential blue water availability over the period 2000-2010 (baseline conditions). Numbers refer to the months of the year: 001: January, 012: December. The lowest row of maps in each figure represents the water user zones; from left to right: zones of water use for environmental purposes, industrial zones, irrigation zones and urban zones.



(a) WSI based on mean potential blue water availability in the P10T90 scenario



(b) WSI based on mean potential blue water availability in the P90T10 scenario

Figure 12 Monthly Water Stress Index (WSI) maps of Suquía River Basin, based on mean potential blue water availability under the climate change scenarios P10T90 (a) and P90T10 (b). Numbers refer to the months of the year: 001: January, 012: December. The lowest row of maps in each figure represents the water user zones; from left to right: zones of water use for environmental purposes, industrial zones, irrigation zones and urban zones.

Figure 12 shows the spatial distribution of the WSI under the P10T90 and P90T10 scenarios of climate change, with respectively a small and large increase in precipitation, and conditions with larger and smaller increases of mean annual temperature (see chapter 2.5 for the description of the climate change scenario's). The maps show little variation in the level and spatial distribution of WSI between the baseline conditions (Figure 11b) and the climate change scenarios. It should be noticed that the WSI for the climate change scenarios was calculated using the quantitative water demand under the baseline conditions. Future water demand in the river basin depends both on socio-economic developments and climate change. The results of the water stress assessment provided by the WP4-tool demonstrate that climate change only will not influence the level and spatial distribution of water stress conditions in the river basin. The influence of demographic and economic developments and land use change can be assessed with the WP4-tool by entering maps of the projected locations of water user units (urban areas, irrigated areas, industries, mines) and quantitative water demands of these units in the look-up tables (see chapter 3.2 on the Water Demand Assessment Tool). This type of information was not available for the COROADO study sites, and requires modelling of land use change and evolutions in water demand. This task was outside the scope of WP4. However, the WP4-tool can be used to explore the influence of socio-economic development and land use change by entering spatial scenarios of water users in the river basin, with estimated water demands, as explained above.

Water stress mapping – all case study areas
Since the WSI is based on generic characteristics of water systems, that can be established for any river basin, the values of the WSI can be compared between the COROADO case study areas. Figure 13 shows the maximum catchment-average value of the WSI in the case study areas under baseline conditions and two scenarios of climate change. The WSI is depicted for the growing period in each area and the remaining period of the year, and for different conditions of the potential blue water availability in each region, averaged over the 10-year period of model simulations with the PCRGLOBWB model (i.e. the period 2000-2010 for the baseline simulation, and a 10-year period centred around 2050 for the simulations of climate change).

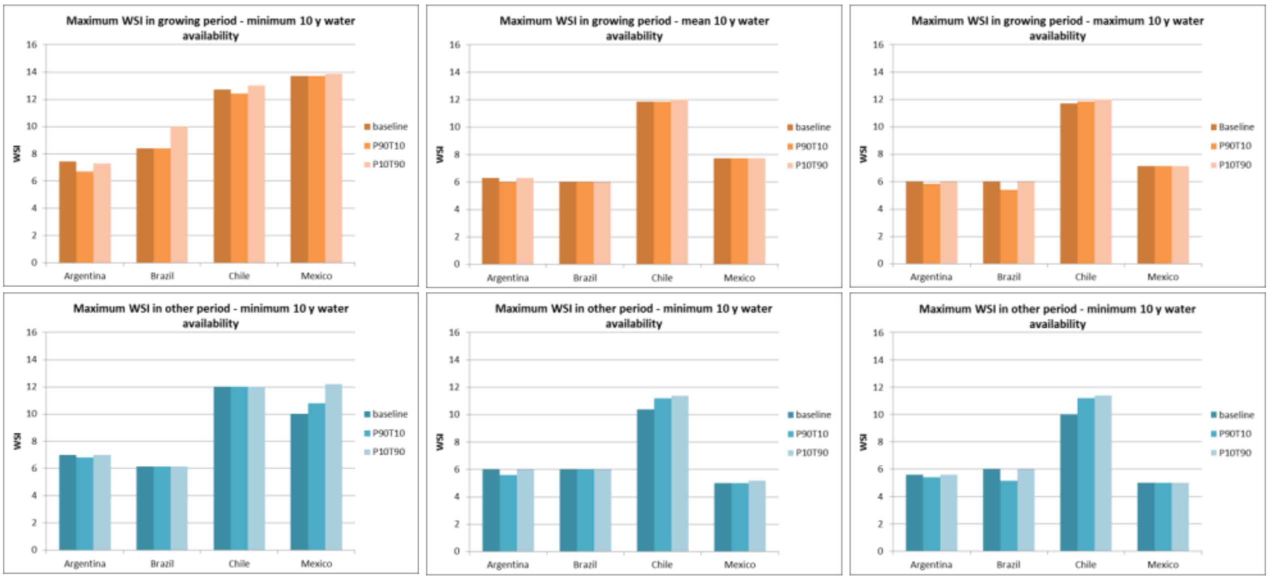


Figure 13 Maximum catchment-averaged WSI in the COROADO case study areas under baseline conditions and the climate change scenarios P10T90 and P90T10, in the growing period for each river basin (orange) and the remaining period of the year (blue). WSI based on minimum (left), mean (middle) and maximum (right) potential available blue water over the 10-year period of model simulations with the PCRGLOBWB model.

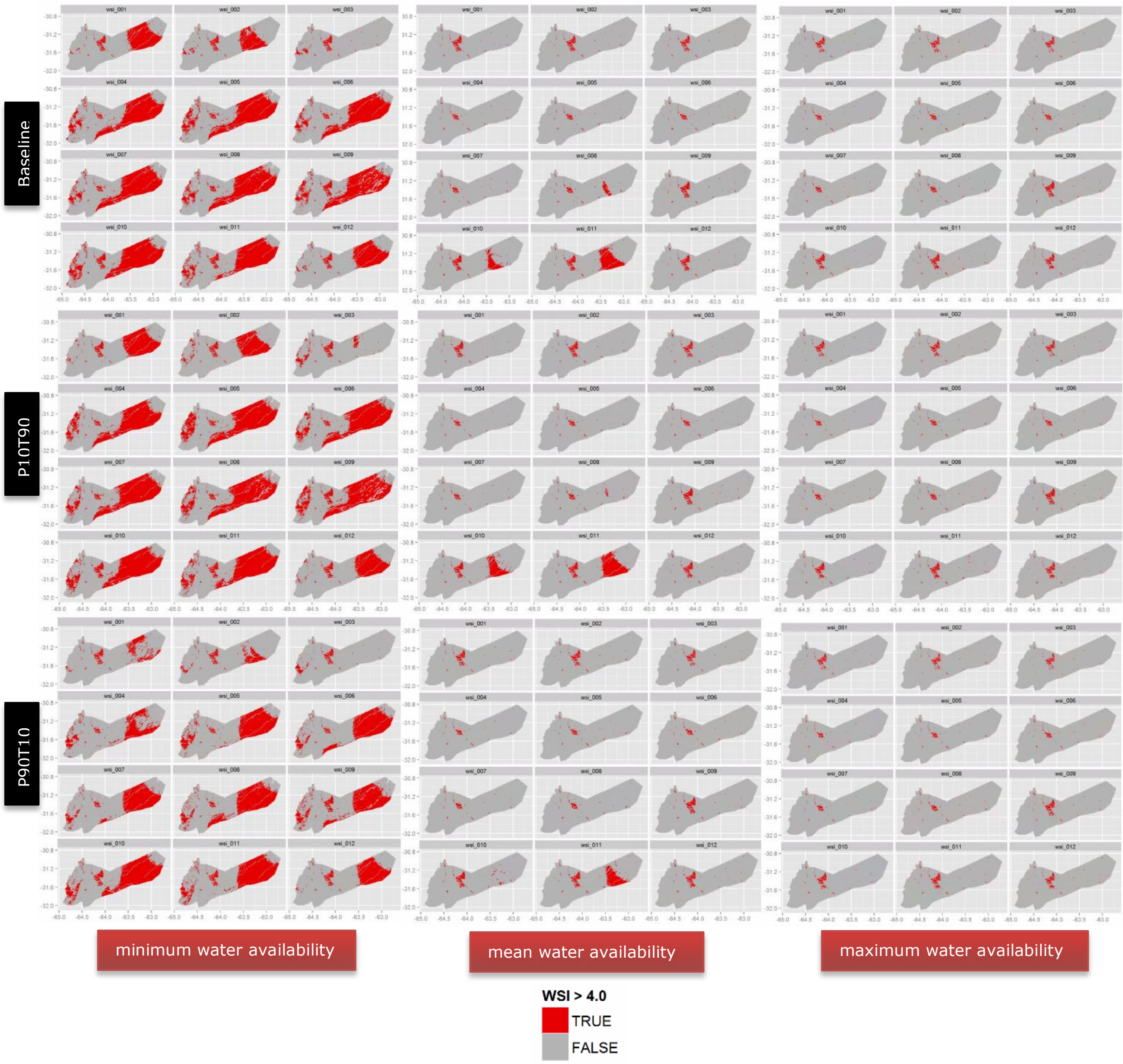
Figure 13 shows that the level of water stress as indicated by the WSI is highest in the Chilean case study area, despite the fact that water users in this area are closer to water supply points than in the other areas. This is caused by the high water demand compared to the low potential blue water availability in this area, if we consider only the renewable water sources. In the case study area in Mexico, the level of water stress is also high compared to the other areas, especially when the minimum blue water availability is considered. This can be explained by the large water demand of the irrigation district DR025, that is located at larger distances from inlets and irrigation channels than irrigated areas in the other study sites. Overall, the level of water stress is slightly higher in the growing period than in the other period of the year due to the demand for irrigation water. This does not apply to the case study area in Brazil, where agricultural water demand is low compared to the demand for urban/domestic and industrial use (Del 2.1, Porto et al., 2012).

The influence of the climate change scenarios on the level of water stress is small compared to the influence of the variability in potential available blue water within the 10-year periods considered. In the cases where the WSI changes between climate scenarios, WSI is highest in the P10T90 scenario, as expected, since in this scenario represents changes in precipitation at the 10th percentile of the frequency distribution of the considered climate change models, and changes in temperature at the 90th percentile (see chapter 2.5).

The water stress assessment tool also gives information on the spatio-temporal distribution of the WSI in regions. Figure 14, Figure 15 and Figure 16 give the areas with values of the WSI larger than 4 in the case study areas, as a function of variations in available blue water flow at three temporal scales: climate change scenarios until 2040-2050, statistics of flow conditions over a 10-year period, and month of the year. The value of 4 was chosen as a threshold value halfway the range of values of the WSI found for the 4 case study areas (from 0 till 8). Interpretations on the spatio-temporal distribution of the WSI in the areas is given in the text boxes below the figures. The images are not shown for the area in Chile shown, since only a few pixels with values of the WSI larger than zero appear in these maps, and they are therefore not easy to read. The reason that only a few pixels have WSI values larger than zero in this area is that the WSI depends on the local relative water demand. At locations where there is no water demand (the major part of the area in the case study area in Chile), the local relative water demand is zero, and consequently WSI is zero.

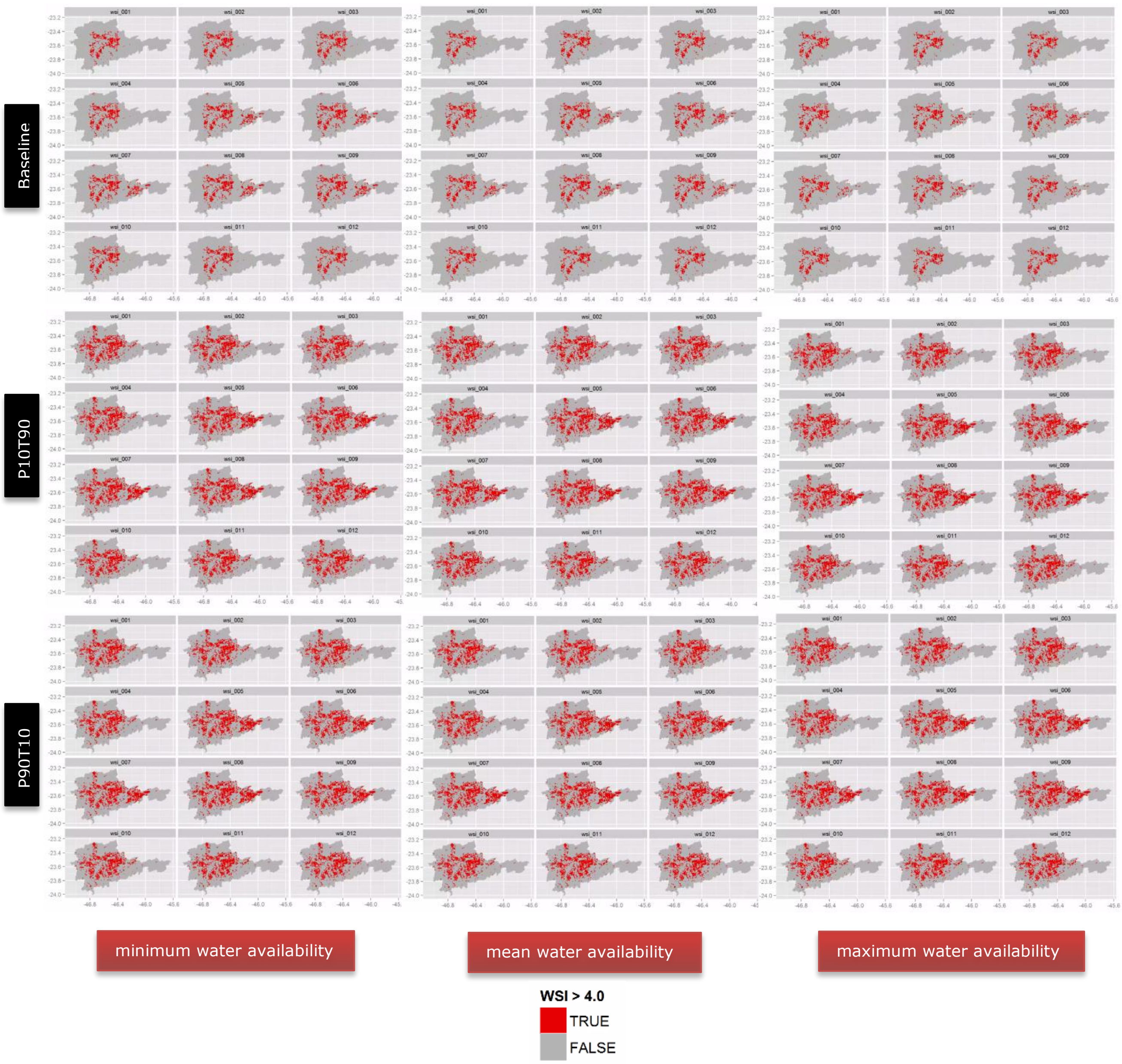
The figures first of all show that significant parts of the 4 case study areas have water stress conditions above the threshold in parts of the year in the baseline situation, especially under conditions of low available water flows. This indicates that water stress caused by high local relative water demands and distance from water supply points is already an issue in the case study areas under current conditions. The influence of the climate change scenarios on the areas with WSI>4 differs between the study sites. In the sites in Argentina and Mexico, the area differs hardly between the baseline and the climate change scenarios. However, in the site in Brazil, the area with WSI>4 increases under both scenarios of climate change compared to the baseline situation. The influence of the climate change scenarios on the area with WSI>4 is larger than the influence of variability in flow within the 10-year period analysed. Since the water demand and the locations of water supply points were equal in the baseline and climate change scenarios, the differing impact of the climate change scenarios on the spatial distribution of the WSI between the case study sites must be attributed to variations in blue water availability between the sites as a result of climate change. Obviously the scenarios of climate change have a larger influence on the water availability in the case study site in Brazil than in the areas in Argentina and Mexico.

The figures also show a large monthly variation of the areas experiencing water stress in the sites in Argentina and Mexico. This is partly because water demand for irrigation imposes water stress conditions during the growing seasons, and partly due to the seasonal variation of available blue water flows. Again, it is stressed that monthly variations of water demand for other water uses (urban/domestic, industrial, mining) were not included in the set-up of the water stress assessment tool due to a lack of data. Of these water uses, the water demand for urban and domestic use is expected to vary within the year due to seasonal variations in weather conditions. Higher temperatures in the summer will cause an increased demand for water for human consumption, domestic use, cleaning of streets and cars and landscape irrigation in urban areas. Including monthly variations in the water demand for urban/domestic use in the WP4-tool for water stress assessment will increase the area experiencing water stress conditions in the summer months .



- The areas with WSI>4.0 are the city of Cordoba, and in the growing season the irrigated areas north and south of Cordoba, and a part of the downstream basin at a large distance of water supply points upstream in the basin. These areas are now supplied by water from the Xanaes river (Santiago Reyna, pers. comm.).
- In years with low flows, the area with WSI>4.0 is significantly larger than in years with average or high flows.
- In years with low flows, some areas in the upstream part of the basin also experience water stress.

Figure 14 Areas with WSI>4 (red, ' TRUE') in the case study area in Argentina as a function of flow conditions (over a 10-year period), climate change scenario and month of the year.



- Under both scenarios of climate change, the area with WSI>4.0 increases compared to the baseline situation. The area with WSI>4.0 is largest in the P10T90 scenario.
- The influence of the climate change scenarios on the area with WSI>4.0 is larger than the influence of variability in flow within the 10-year period. This is different from the situation in the case study area in Argentina, where the influence of annual variability is larger than the influence of the climate change scenarios.
- The area with WSI>4.0 varies hardly between the months of the year, since the demand for urban/domestic and industrial use is assumed constant over the year. Only in the growing season (May-Sep) the area extends in the eastern part of the basin as a result of water demand for irrigation.

Figure 15 Areas with WSI>4 (red, ‘ TRUE’) in the case study area in Brazil as a function of flow conditions (over a 10-year period), climate change scenario and month of the year.

- The area with WSI>4.0 is similar in all climate scenarios, and under minimum and maximum available water flow in the simulated 10-year periods. This indicates that the demand is so high compared to the available water and the distance to supply points, that variations in the latter are not reflected in the variation of the WSI.
- WSI is larger than 4 in 75% of the irrigated area, and 50% of the urban area.
- The area with WSI>4.0 varies greatly within the year, with the irrigated area taking up a large part of the basin between Janary and September.

Figure 16 Areas with WSI>4 (red, ' TRUE') in the case study area in Mexico as a function of flow conditions (over a 10-year period), climate change scenario and month of the year.

Water stress assessment for economic sectors

The maps of the water stress index generated by the WP4-tool give insight in the spatial distribution of water stress conditions in the region under consideration, but not on the water stress conditions of different economic sectors using water in the region. For this purpose, the WP4-tool can generate so-called 'violin plots' and empirical cumulative density functions of the water stress index, using an R- script. The violin plots for the four case study areas are included in Annex 1.10.

The violin plots show the 10-year averaged probability density of the WSI at different values for each month of the year for the water user zones in the region, as defined in the Water Demand Assessment Tool explained in Chapter 3. The water uses considered include water use for urban and domestic purposes, industry, mines and agriculture. Environmental water requirements were considered for the case study area in Argentina, for which a minimum required river flow was provided. As examples, the violin plots for the case study area in Argentina are shown in Figure 18, Figure 19 and Figure 20 for the baseline conditions (2000-2010). The plots show that the probability density of the WSI is distributed in two ranges: a higher range representing the majority of the values, and a small range with values of WSI near 0. This applies to the violin plots for all case study areas (Annex 1.10). The higher ranges represent the WSI occurring in the water user zones. The lower ranges represent cells located in water user units that are close to, or even overlapping with water supply points. Examples are the pumping wells supplying groundwater to the irrigated areas in Copiapó river basin, which are located in the irrigated areas (Figure 17).

The violin plots for the Argentinian case study area show that the highest WSI values occur in the zones with irrigated agriculture (up to 6.5 in the period September-November), and in this period, the range of values is largest. However, in the off-season (April-August), the WSI is higher in the urban settlements, with most values between 4 and 6. It should be noted that the 10-year averaged monthly variation of the WSI in the violin plots for the urban/domestic water use is only based on the monthly variation in potential blue water availability, since information on the monthly variation in water demand (approximated by actual water use) was not available. The same applies to the monthly variation of irrigation water demand within the period of irrigation. As explained in chapter 3, this information, once available, can be easily incorporated in the tool to produce figures representing the water stress index including the monthly variation of water demand for all sectors. It is also possible to derive water demand estimates from model approaches (see chapter 3.1), or from the irrigation assessment tool from WP5 (available in the COROADO DSS at http://coroado.tk).

A seasonal influence is also visible in the WSI values for environmental flow requirements and urban/domestic use, where the 'violins' of the WSI values are slightly shifted upwards along the y-axis of the plots between August and November. This is the spring period after the dry season, when precipitation is first consumed for filling up the stores in the groundwater and soil reserves, or by evapotranspiration due to increasing temperatures, before becoming available in the form of surface runoff and baseflow.

Figure 17 Water user zones (mines, urban/domestic and irrigated agriculture) and water supply points in Copiapó River Basin, Chile.

The zones with urban/domestic use are characterised by the largest spread in the values of WSI (1-6, versus 1.5-3 and 2.5-6.5 for irrigated agriculture, and 1.5-3.8 for environmental flow requirements). The reason for this is that some urban settlements, especially the ones downstream of Cordóba city, are at a large distance from water supply points, while others are very close (Figure 6 and Figure 10).

When comparing the violin plots for the WSI obtained with the mean monthly potential blue water availability over the 10-year period (Figure 19) to those obtained from the minimum (Figure 18) and maximum blue water availability (Figure 20), we see that the 'violins' are positioned highest on the Y-axis for the minimum blue water availability, and also are more 'stretched' than the violins obtained with the mean and maximum blue water availability. This happens for all three water using sectors. This indicates that water stress conditions are more severe under conditions of low potential blue water flows, and that the spatial variability in these conditions is also larger.

The violins are differently shaped between the water using sectors. The mushroom shape of the violins for environmental flow requirements indicates that the majority of cells in the river basin has high values of the WSI, although smaller than for the other water using sectors most of the year. This can be explained by the relative large distance to water supply points of the cells in the central part of the catchment, between Cordóba city and Mar Chiquita. It could be argued that the water quality of the Suquía River downstream of Cordóba City at some point along the river becomes sufficient to supply environmental flow demands, and even urban settlements in the downstream area, but the literature contradicts this (e.g. (Pasquini, Formica, & Sacchi, 2011), (Merlo et al., 2011)).

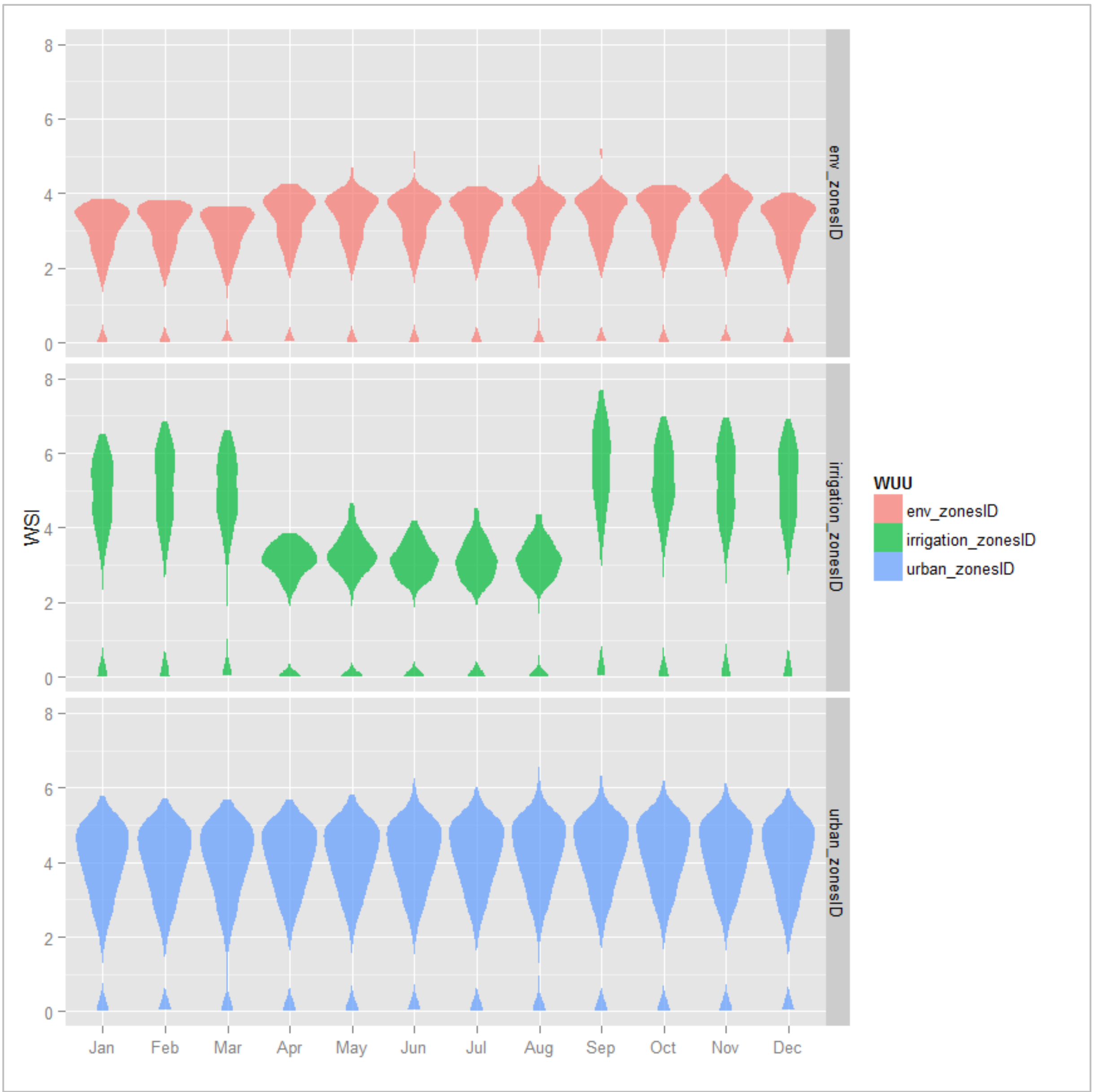


Figure 18 Violin plot of the water stress index for the case study area Argentina for main water using sectors, based on the minimum potential blue water availability over the period 2000-2010 (baseline conditions). Env_zonesID: environmental flow requirements, irrigation_zonesID: irrigated agriculture, urban_zonesID: urban/domestic water use.

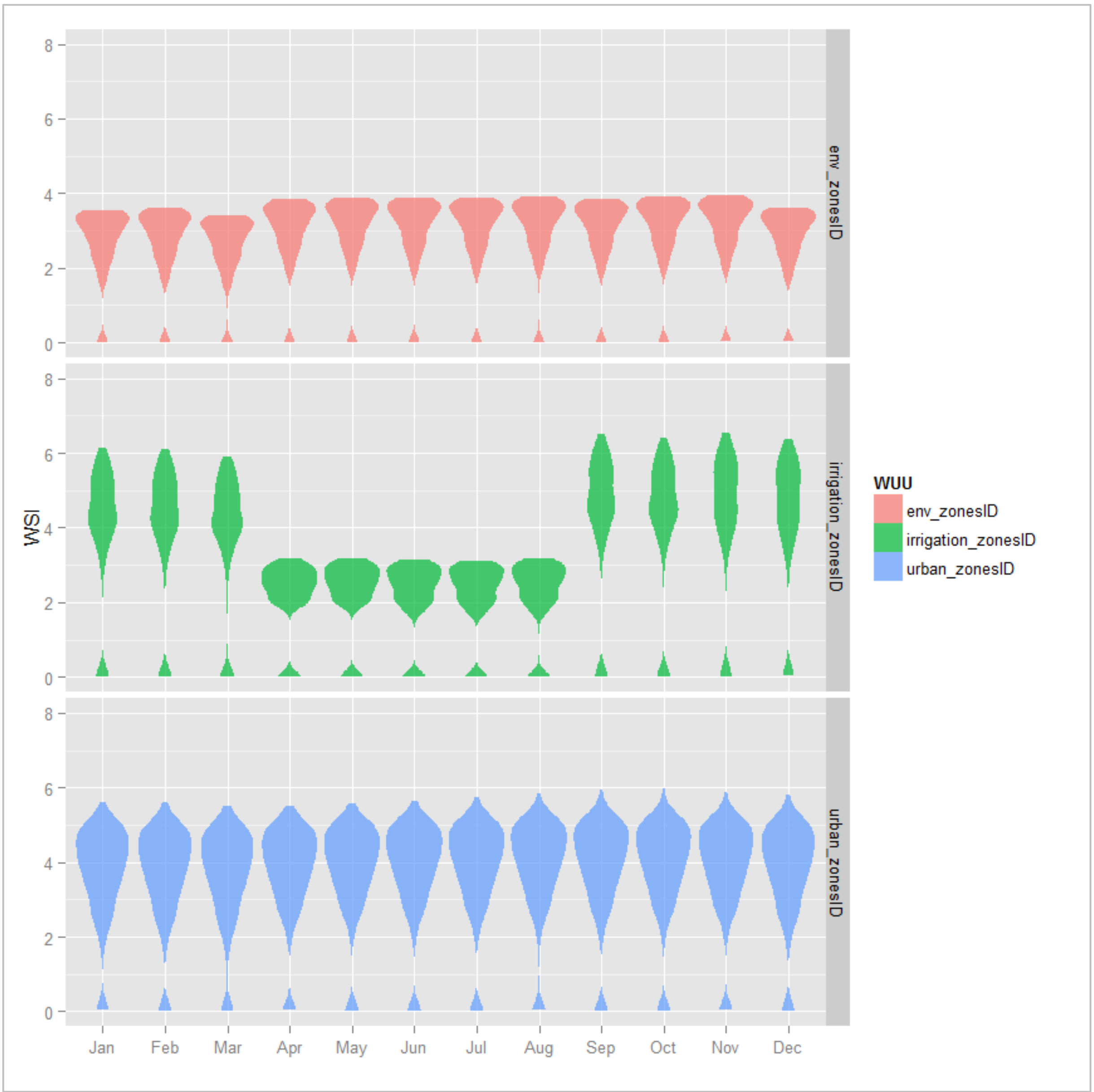


Figure 19 Violin plot of the water stress index for the case study area Argentina for main water using sectors, based on the mean potential blue water availability over the period 2000-2010 (baseline conditions). Env_zonesID: environmental flow requirements, irrigation_zonesID: irrigated agriculture, urban_zonesID: urban/domestic water use.

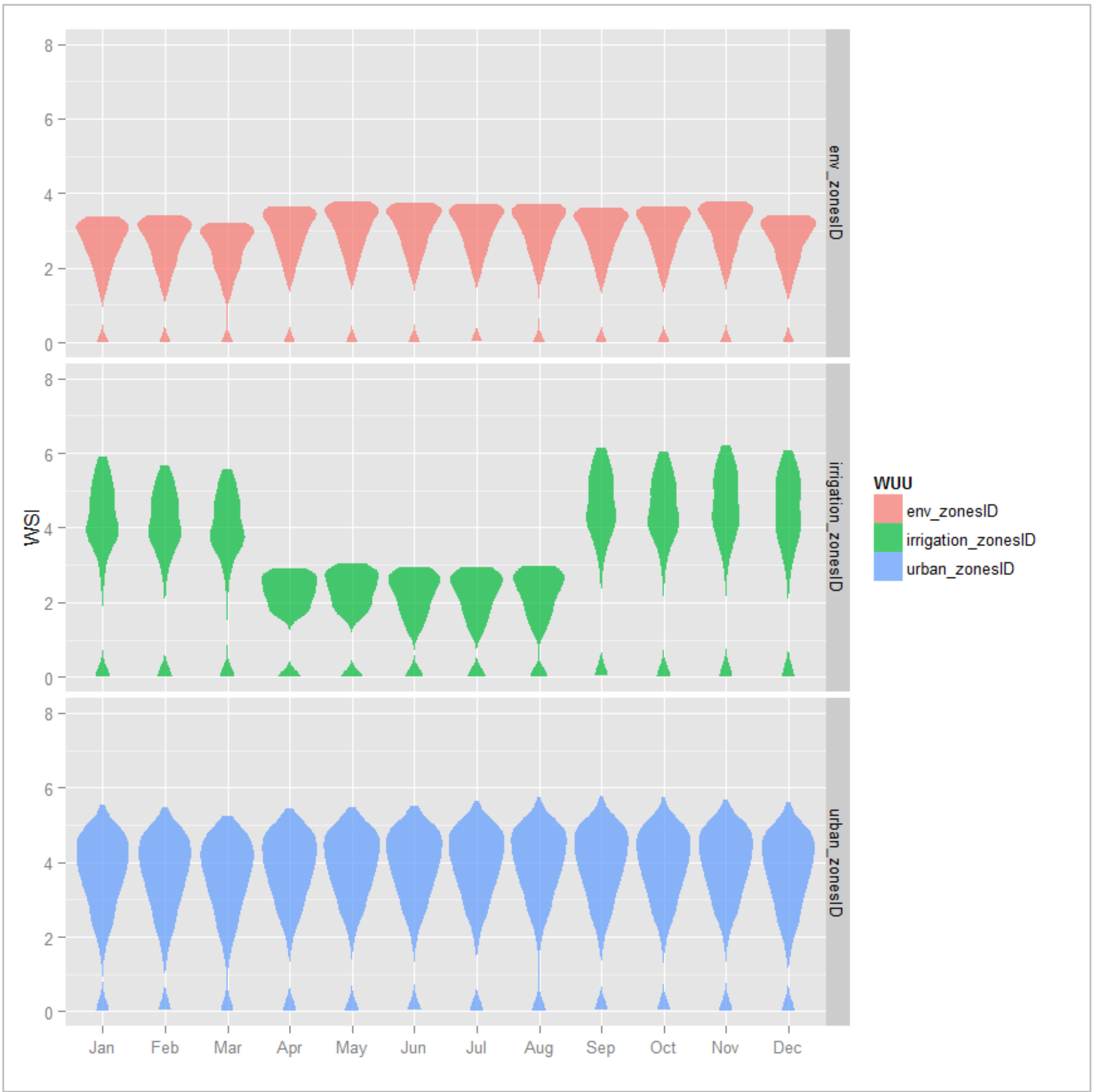


Figure 20 Violin plot of the water stress index for the case study area Argentina for main water using sectors, based on the maximum potential blue water availability over the period 2000-2010 (baseline conditions). Env_zonesID: environmental flow requirements, irrigation_zonesID: irrigated agriculture, urban_zonesID: urban/domestic water use.

The violin plots for the agricultural sector show a bi-modal density distribution of the WSI, reflecting the water stress conditions in the irrigated agricultural zones north and south of Cordóba City. The upper part of the violin's 'bulge' reflects the WSI index in the northern area, where water use is slightly higher than in the southern area (Figure 7). The violin plots for the water user zones in urban areas have a more continuous shape, with the bulge of the violins at the higher end of the range of WSI values. This part of the density distribution reflects the cells located in and around Cordóba City, where the majority of cells with water use for urban and domestic purposes are located (Figure 6), and where water demand is highest per unit area of all sectors (Figure 7).

A comparison of the violin plots between the baseline conditions and scenarios of climate change show that water stress conditions as indicated by the WSI change only marginally due to changes in potential blue water availability as a result of climate change, even for the most extreme scenarios (Figure 21).

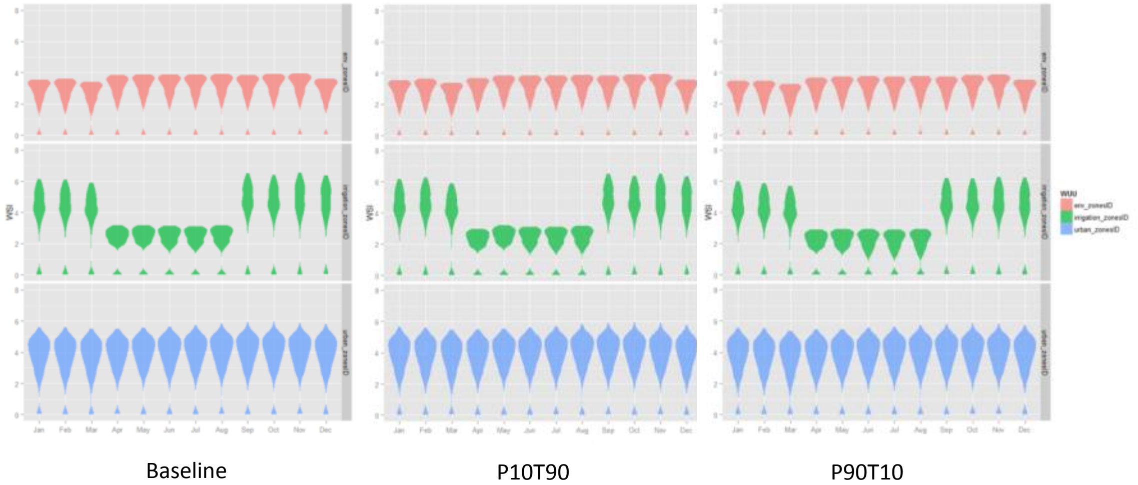


Figure 21 Violin plot of the water stress index for the case study area Argentina for main water using sectors, based on the mean potential blue water availability over a 10-year period under baseline conditions (2000-2010) and centred around 2050 according to the climate change scenarios P10T90 and P90T10. Env_zonesID: environmental flow requirements, irrigation_zonesID: irrigated agriculture, urban_zonesID: urban/domestic water use.

The empirical cumulative density functions (ECDF) indicate the distribution of WSI values over the zones where water use for different sectors is situated (environmental water use, irrigated agriculture, urban areas and settlements). Examples for the Argentinian case study area are shown in Figure 22 for the baseline conditions. When comparing the ECDFs between water using sectors, the largest values of the WSI and also the largest range of values of the WSI are observed for irrigated agriculture and urban/domestic water use, at least in the period September-March, corresponding to the growing season.

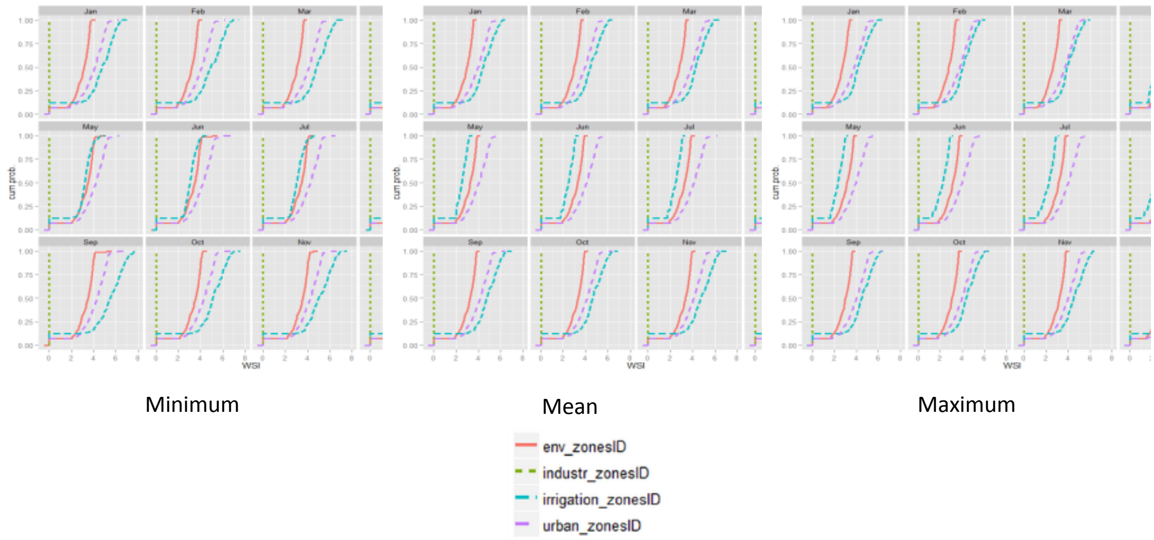


Figure 22 Empirical cumulative density functions of WSI for main water using sectors in the case study area in Argentina, based on the potential blue water availability over the period 2000-2010 (baseline conditions). Env_zonesID: environmental flow requirements, irrigation_zonesID: irrigated agriculture, urban_zonesID: urban/domestic water use.

In the period April-August, the ECDF for irrigated agriculture shifts left from the ECDFs of environmental water use and urban/domestic use, indicating that water stress conditions are less severe for this sector in this period of the year. The steepest ECDF is observed for the industrial sector, that covers only a few cells (km^2) in the area, where the WSI is very small, since the industrial plant takes its water from the Suquía River and from the groundwater at locations very close to the plant, and consequently the friction-distance is very small. When comparing the ECDF for a water using sectors between conditions of

This work was funded by the COROADO project (www.coroado-project.eu) under the EU 7th Framework Programme

minimum, mean and maximum potential available water flow, the ECDF shifts to the left, indicating that lower values of the WSI occur when water availability increases.

The ECDFs can also be used to derive information on the area of the river basin covered by WSI values of given percentiles for each water using sector, e.g. the 25th, 50th and 75th percentiles. Figure 23 shows the WSI at the 50th cumulative percentile of areas occupied by the main water using sectors in the case study areas: irrigated agriculture, urban/domestic use and environmental flow requirements (for the area in Argentina only), and mining (for the area in Mexico only). For the case study area in Argentina the results are shown for the baseline, P10T90 and P90T10 scenarios; for the areas in Brazil and Mexico the results are shown for the baseline scenario. The results can be compared between case study areas, between water using sectors, between flow conditions (10-year mean, minimum and maximum flows) and between climate change scenarios (for Argentina in this figure).

Figure 23 shows that at 50% of the observations (cells) within the water using sector irrigated agriculture, the WSI is highest in the Mexican case study area, with values up to 6.5. The case study areas in Brazil and Mexico have zero values of WSI at the 50th percentile in periods of the year, whereas in the area in Argentina, WSI at the 50th percentile is still between 2 and 3 in the areas with irrigated agriculture. This is because the WSI is calculated based on the total water demand from all sectors for each cell. In the areas in Brazil and Mexico, there is no water demand for irrigated agriculture in the periods indicated by the teams from the study sites (Jan-Apr/Oct-Dec for Brazil, and Sep-Dec for Mexico). In the areas mapped as zones with irrigated agriculture, no demand from other water using sectors is modelled. In the Argentinian case study area, an environmental flow demand is attributed to each cell in the area, based on the requirement in the river channel, as explained in chapter 3.

For the urban and domestic water using sector, WSI values are highest in the Mexican case study area, with values between 4 and 5, compared with values around 4 and 3 for the areas in Argentina and Brazil respectively. This indicates that the water stress conditions as determined by the local relative water demand and distance from water supply points are most severe in the Mexican case study area.

Variations in the WSI at the 50th percentile as a result of differences in climate forcing are illustrated for the area in Argentina. These variations are small compared to the variations due to the variability in available water flows over the 10-year period (minimum, mean and maximum available blue water flow, indicated with different shades in Figure 23). These results suggest that in this case study area, annual variations in available blue water flows have a larger influence on water stress conditions than variations in climate according to future projections.

As expected, conditions of minimum available blue water flows over the 10-year period cause the largest values of the WSI, whereas conditions of maximum available flow yield lower values of the WSI. Considering the differences between flow conditions over all case study areas and all water using sectors, variations in the WSI due to flow conditions are largest for the water using sector irrigated agriculture, with up to one unit of change. This indicates that this sector is the most sensitive to annual changes in blue water availability.

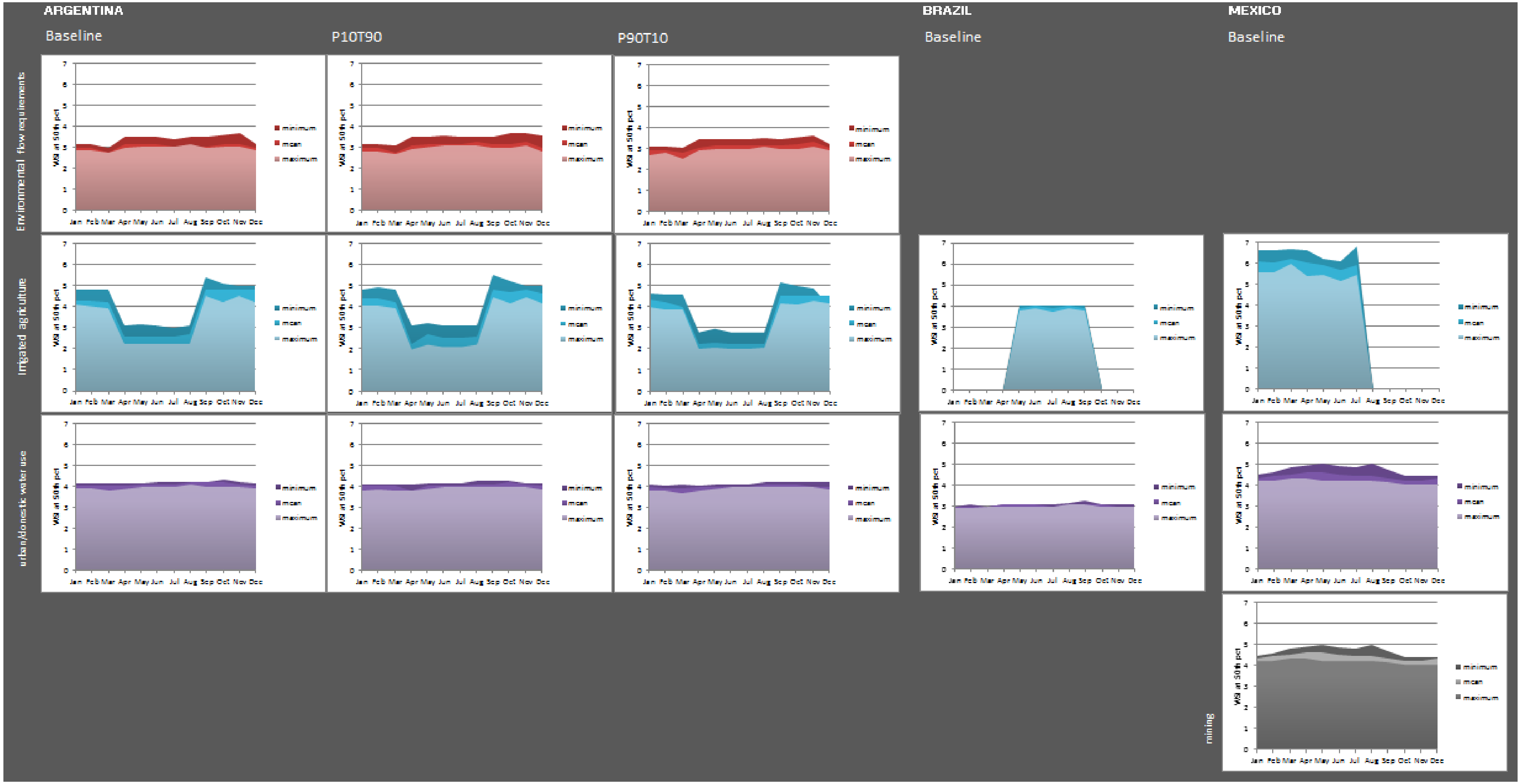


Figure 23 50th percentile of WSI for water using sectors in the case study areas.

For the case study area in Brazil the 50th percentile values of WSI are not included for the industrial and mining sectors, since for these sectors WSI only becomes >0 at resp. 70% and 80% of the area. This means that for these sectors, only a small part of the areas occupied has high water stress. This is because industrial and mining plants often have their water supply point on site, as a result of which the friction-distance is low, and consequently the WSI is low in the larger part of the areas occupied by these water users. However, for both sectors have areas with high water stress (up to 5.5), as is indicated by the violin plots in Figure 24 below.

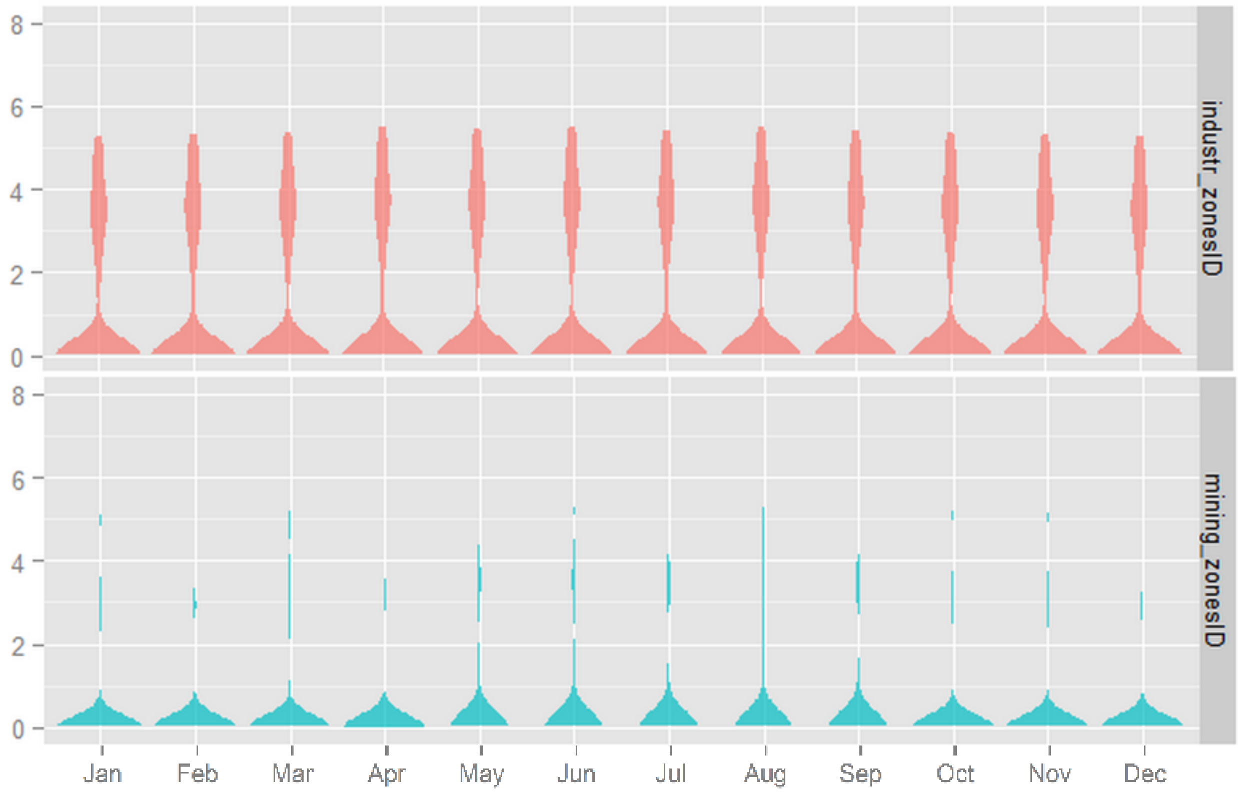


Figure 24 Violin plots of WSI for the industrial and mining sectors, Brazil, baseline scenario.

For the case study area in Chile the 50th percentile values of the WSI are not shown, since the major part of the main water using sectors is located close to the water supply points, at distances smaller than the cell size used in the water stress assessment tools. Therefore the 50th percentile of the WSI is 0. However, high levels of water stress are obtained in the water user units located at some distance of the water supply points (up till 6.9 for the mining sector and 7.8 for irrigated agriculture) (Figure 25).

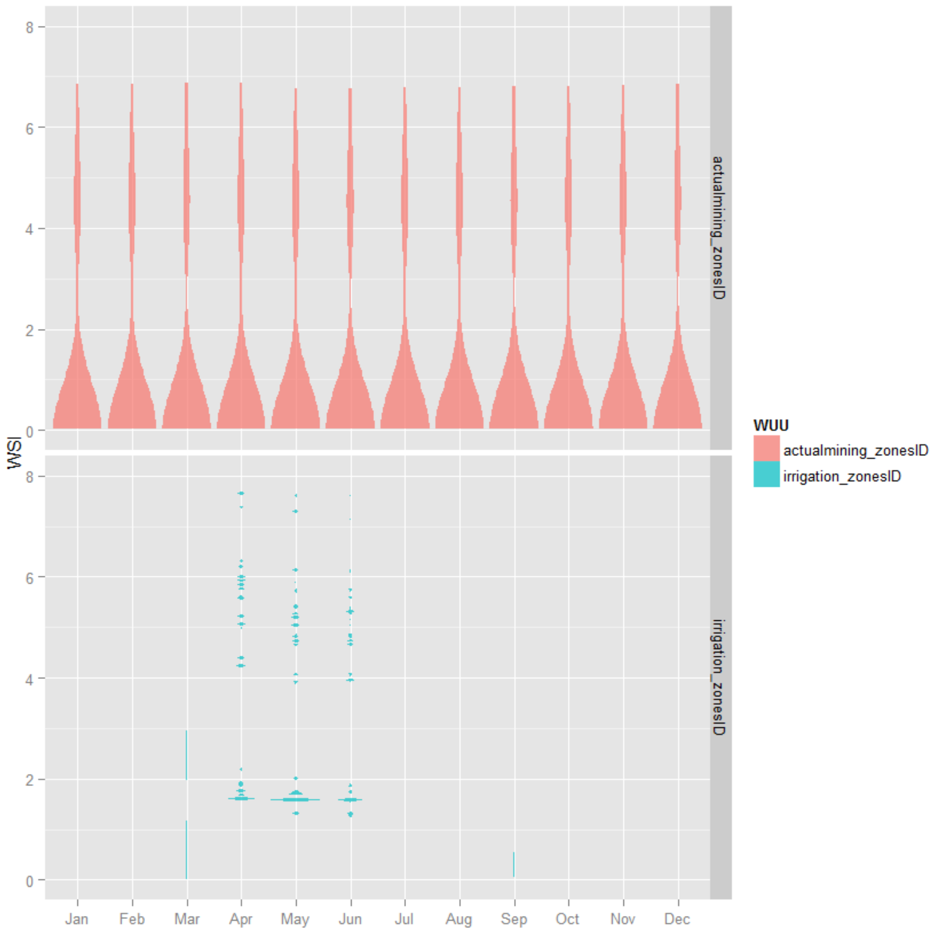


Figure 25 Violin plots of WSI for the industrial and mining sectors, Chile, baseline scenario.

As was already shown for the map and violin plot representations of the WSI for the case study area in Argentina, the WSI is only marginally affected by climate change as reflected in the climate change scenarios employed in the WP4-tool (Figure 26). This indicates that water stress conditions of the main water using sectors in this area will not change much as a result of climate change only, not in space, and not within the year. We emphasize that including information on changing water demand, as a result of socio-economic changes, but also as a result of climate change, is likely to influence water stress conditions. In order to analyse the influence of changing water demand on the WSI, information on changing water demand under future conditions can be entered into the WP4-tool. The location and extent of water user zones can be entered in the form of maps, and the magnitude and monthly variation of water demand can be entered in the look-up tables.

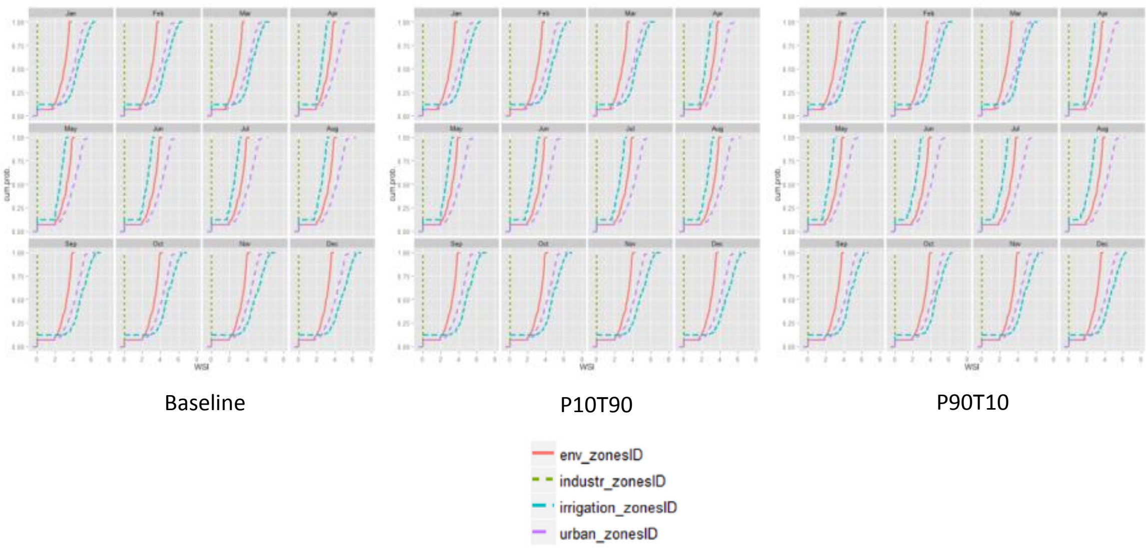


Figure 26 Empirical cumulative density functions of WSI for main water using sectors, based on the mean potential blue water availability over a 10-year period under baseline conditions (2000-2010) and centred around 2050 according to the climate change scenarios P10T90 and P90T10. Env_zonesID: environmental flow requirements, irrigation_zonesID: irrigated agriculture, urban_zonesID: urban/domestic water use.

4.3 References

Alcamo, J., Henrichs, T., & Rösch, T. (2000). *World Water in 2025 World Commission on Water for the 21 Century*.

Aronne, I. D., & Jacomino, V. M. F. (2002). *Analysis of the Political and Legal Framing Conditions with Regard to Environmental Issues Relevant to the Energy Sector* (pp. 1–24). Belo Horizonte, Brazil. Retrieved from http://www.dii.uchile.cl/progea/proyectos/grenelem/second/wp2_brazil.pdf

Bär, R., & Lehmann, A. (2012). Integrated water resource sustainability and vulnerability assessment, 1–45.

Brown, A., Matlock, M. D., & Ph, D. (2011). A Review of Water Scarcity Indices and Methodologies.

Falkenmark, M., & Lindh, G. (1976). *Water for a Starving World*. Westview Press. Retrieved from http://books.google.nl/books?id=u0S7AAAAIAAJ

Merlo, C., Abril, a, Amé, M. V, Argüello, G. a, Carreras, H. a, Chiappero, M. S., … Solís, V. M. (2011). Integral assessment of pollution in the Suquía River (Córdoba, Argentina) as a contribution to lotic ecosystem restoration programs. *The Science of the Total Environment*, *409*(23), 5034–45. doi:10.1016/j.scitotenv.2011.08.037

Pasquini, A. I., Formica, S. M., & Sacchi, G. a. (2011). Hydrochemistry and nutrients dynamic in the Suquía River urban catchment's, Córdoba, Argentina. *Environmental Earth Sciences*, *65*(2), 453–467. doi:10.1007/s12665-011-0978-z

Perveen, S., & James, L. A. (2010). Scale invariance of water stress and scarcity indicators: Facilitating cross-scale comparisons of water resources vulnerability. *Applied Geography*, 1–8. doi:10.1016/j.apgeog.2010.07.003

UN. (2013). Wastewater Management & Water Quality - The Post 2015 Water Thematic Consultation.

US-EPA. (2012). *Guidelines for Water Reuse 2012*.

Van Beek, L. P. H., Wada, Y., & Bierkens, M. F. P. (2011). Global monthly water stress: 1. Water balance and water availability. *Water Resources Research*, *47*(7), n/a–n/a. doi:10.1029/2010WR009791

Vorosmarty, C., Douglas, E. M., Green, P. A., & Revenga, C. (2005). Geospatial Indicators of Emerging Water Stress : An Application to Africa, *34*(3), 230–236.

Wada, Y., van Beek, L. P. H., & Bierkens, M. F. P. (2011). Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability. *Hydrology and Earth System Sciences*, *15*(12), 3785–3808. doi:10.5194/hess-15-3785-2011

Wada, Y., van Beek, L. P. H., Viviroli, D., Dürr, H. H., Weingartner, R., & Bierkens, M. F. P. (2011). Global monthly water stress: 2. Water demand and severity of water stress. *Water Resources Research*, *47*(7), n/a–n/a. doi:10.1029/2010WR009792

Wintgens, T., & Hochstrat, R. (2006). *Integrated Concepts for Reuse of Upgraded Wastewater*. (T. Wintgens & R. Hochstrat, Eds.) (pp. 1–184). Aquarec.

Yu, L. (2013). *Water quality and water treatment*.

5 Matching wastewater producers and re-users (Module 4 and 5)

5.1 Introduction

The objective of the WP4-tool is to develop a spatial tool to support water resource managers in planning water reuse schemes in regions with water demand from various users and sectors, by connecting outputs of wastewater from one water user to meet the input requirements from other users. The actual production of wastewater in a region is one of the basic information blocks in the planning tool.

Anaerobic wastewater treatment of high salinity wastewaters. Source: www.wageningenur.nl.

This chapter describes the modules of the WP4 tool for mapping current wastewater production and potential users of wastewater in regions of Latin-America. Application of the tool finally leads to suggestions for the locations of water reuse schemes that could connect existing wastewater producers to potential reusers. The modules are applied to the four case study areas. These applications are reported in detail in Annex 1.11. The geoinformation layers in which the results are stored were delivered to WP3 and WP6 for hosting on resp. the project's WebGIS and COROADO DSS. The main results of the applications are summarized in chapter 5.3.

5.2 Method

Modules 4 (Find wastewater producers) and 5 (Find potential reusers) consist of procedures to map locations and information on actors in the region who either produce wastewater and/or could potentially reuse treated wastewater. This mapping is eventually used to support the planning of potential locations of water reuse schemes at the regional level; i.e. to identify potential locations and actors in future water reuse schemes in the region. It should be noted that the method is not suitable for a detailed feasibility analysis for water reuse schemes. For that purpose, advanced tools and methods are available from the literature (e.g. (Wintgens & Hochstrat, 2006), (Ullmer, Kunde, Lassahn, Gruhn, & Schulz, 2005), (McDlelland, 2011), (Krovvidy, 1998)). Instead, the purpose of the WP4-tool is to provide a first indication of zones with potential for water reuse schemes. The information and analysis on the case study areas presented in this chapter and in Annex 1.11 should therefore be considered as a first approach for the final design of WR&R schemes.

The modules are not separate pieces of software, but are steps and guidelines for collecting and analysing spatial information on these actors, using available GIS and spreadsheet software. For the illustration of the application of the procedures and guidelines ArcGIS software from ESRI was used, and MS Excel for the calculations.

The steps for data collection and analysis in modules 4 and 5 are listed in

Table 1. The first two steps consist of the collection and registration of information on water abstraction and wastewater discharge by various actors in the region: municipalities, WWTPs, industries, agricultural areas, mines. Data on water abstractions are usually available from water departments of regional authorities or from water companies. Information on locations and quantities of wastewater discharge are usually more difficult to obtain. The same applies to information on the quality of water abstracted and discharged. Water quality is an important factor in the planning of water reuse schemes, since it determines the types of water treatment technologies required to match the quality desired by a reusing party to the quality of the effluent provided by a wastewater producing party (chapter 6). In case no information is available on the quality of water abstracted or discharged by or for certain water uses, water quality information can be used from comparable users or producers in other regions in the world. Such information was collected for the WP4-tool and is available in the Annexes of chapter 6.

Table 1 Steps for data collection and analysis in Modules 4 and 5 of the WP4-tool.

Step	What specifically?	How to register information	Data sources to use
1. Collect locations of water abstraction by water users and information on water abstracted	Locations: groundwater wells, intake points at rivers or reservoirs, intake points for irrigated areas, intake points from desalination plants Water abstracted: quantity and quality	Register locations in ArcGIS; store information on water abstracted in attribute tables Distinguish between water sources (groundwater, surface water, reclaimed water) Use generic water quality classes (Annex 1.13) if information on water quality is available	Existing (spatial) information from regional water departments and research institutes, statistical agencies Spatial information on water supply infrastructure, land use, population density and connection to water supply networks Google Earth Annual reports from industries and water companies, purification plants Formal and informal registrations of water users from municipalities Permits for withdrawal of surface and groundwater
2. Collect locations of wastewater production by water users and information on wastewater produced	Locations: discharge points into water bodies of industries and wastewater treatment plants; locations of large septic and absorption underground tanks; drainage points of agricultural areas; injection and infiltration points in groundwater Wastewater produced: quantity and quality; information on shares collected and treated, population served (in case of WWTP)	Register locations in ArcGIS; store information on water abstracted in an attribute table Use generic water quality classes (Annex 1.13) if information on water quality is available	Existing (spatial) information from regional water departments and research institutes Spatial information on land use, population density and connection to sewerage network Annual reports from wastewater treatment plants, industries and municipalities Regulations and permits for wastewater discharge
3. Plot wastewater discharge locations in the region in a map	Use scaled symbols to display the wastewater production volumes		Use geoinformation and attribute information from steps 1 and 2
4. Plot water use locations in the region in a map	Use scaled symbols to indicate water demands		Use geoinformation and attribute information from steps 1 and 2
5. Identify existing wastewater reuse schemes in the region	Identify the following components for each scheme: - Wastewater producers (i.e. municipal WWTPs) - Current reusers and type of use (e.g. irrigated agriculture)	Register locations and infrastructure of existing wastewater reuse schemes in ArcGIS; store information on producers, influents, effluents, treatment facilities and destinations in attribute table.	Existing (spatial) information from regional water departments and research institutes Google Earth Information on water reuse scheme from private parties exploiting schemes

Step	What specifically?	How to register information	Data sources to use
	- Effluents quality, after treatment and before reuse (A-E class, see Annex 14.1) - Distance from generation to reuse (km) - Wastewater quality (Main Legal Discharge Standards)		
6. Identify large wastewater producers and large consumers	Examples of large producers: Wastewater treatment plants, irrigated areas, large industries Consider also freshwater resources that are currently not used due to quality constraints Examples of large consumers: irrigated agriculture, urban areas, mines Evaluate if there is a surplus of wastewater produced Evaluate which potential reusers could and would be willing to use the surplus wastewater, using information on preferences from users in the regions from stakeholder consultations Evaluate if quality class of produced wastewater matches quality of required water by consumers Evaluate proximity from wastewater generation point to reuse location, following networks of roads and existing infrastructure, avoiding built-up area	Select locations and properties of large wastewater producers and large consumers from steps 1 and 2 Compile information on wastewater producers and water users in an Excel spreadsheet	Search for additional information on water demands from large consumers, e.g. in annual reports from the private sector, or by estimating water demand for urban areas using socio-economic statistics Spatial information on existing infrastructure for water supply and wastewater collection Check water quality standards for the region; for the COROADO study sites these are documented in Annex 1.19 Check available reports on stakeholder consultations on options for water reuse; for the COROADO study sites these are available from WP2 and WP8
7. Sketch potential new WR&R schemes	Sketch potential WR&R schemes connecting wastewater producers and potential reusers identified in step 6	Draw potential WR&R schemes in maps, together with locations of existing WR&R schemes, locations of wastewater producers and potential reusers Store information on potential WR&R schemes in an attribute table (wastewater source, quantity, quality, wastewater destination, quality, distance) Store information on wastewater producers and reusers in an attribute table	Consult regional water managers, research institutes, authorities, water companies, industries, agricultural representatives, municipality boards and other stakeholders on potential reusers, locations of water reuse schemes

The map produced in **step 3** gives a spatial image of the geographical distribution and magnitudes of wastewater flows produced in the region, and of water demand. In regions where wastewater is only partly collected and treated such images give insight in the potential for wastewater reuse, and reveal a picture of the situation in the region with regard to wastewater production, that would not be available from the usual non-spatial statistical information available to regional water authorities. An example is given below for the case study area in Brazil (Figure 1).

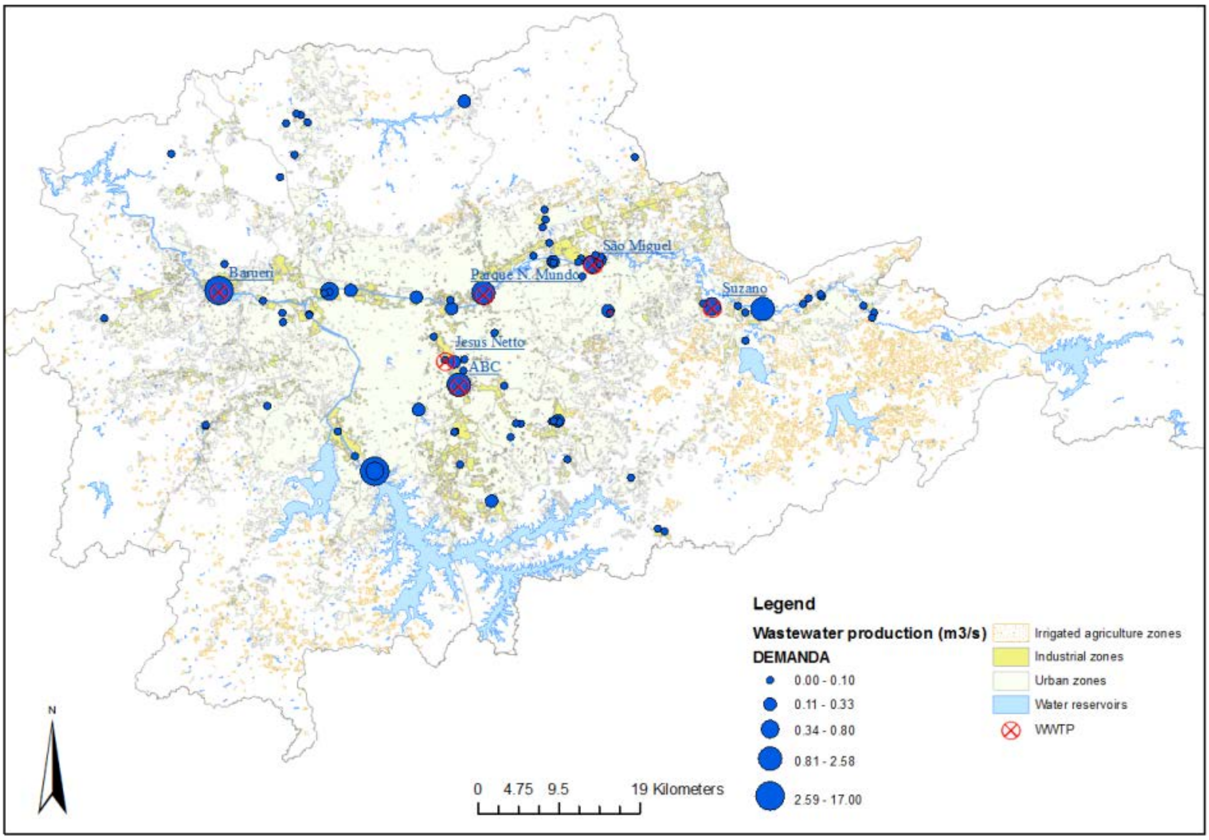


Figure 1. Distribution of wastewater discharge locations from urban and industrial sources in the SPMR. Source: water discharge permits from DAEE (2009).

The information on flows and quantities required by water users in the attribute tables allow an easy retrieval of statistics on the total volumes of wastewater produced in a region and the division over economic sectors. The information on water quality of effluents (if available) gives information on the wastewater production locations that require attention of authorities for safeguarding environmental conditions, and give insights in the efforts required in putting water treatment facilities to enable water reuse by other actors in the region.

The map produced in **step 4** gives a spatial image of the geographical distribution of water users in the region and their water demands, and the current abstractions from different water sources. In one image it reveals the proportions of abstractions from different sources, e.g. from surface water versus groundwater, and the proportions between abstractions by different economic sectors (e.g. urban/domestic versus agriculture). An example of the map resulting from step 4 is given for the case study area in Brazil below (Figure 2).

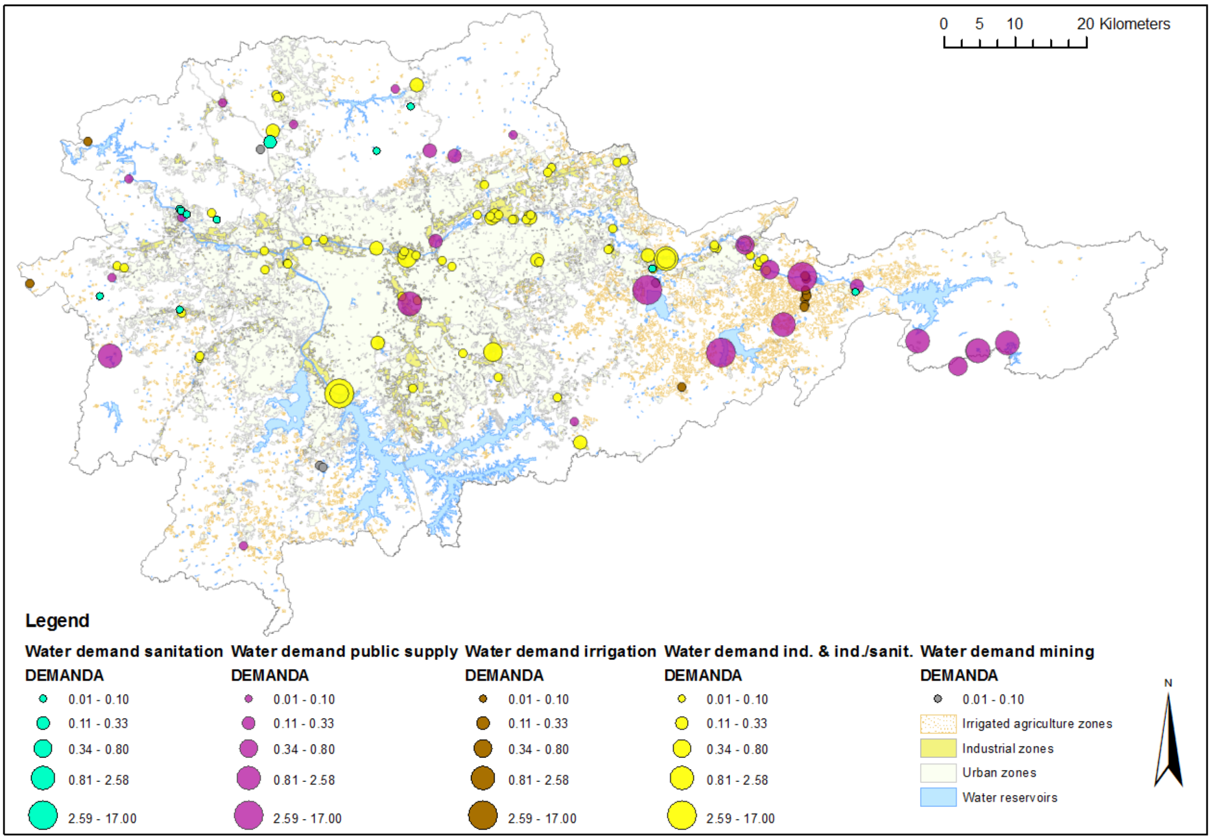


Figure 2 Distribution of water demand locations from surface water bodies by different sectors in the SPMR, according to permits. Source: DAEE (2009).

Steps 5 and 6 lead to the identification of potential wastewater reusers in the region. First the existing WR&R schemes in the area are considered (step 5), since these could offer opportunities to make use of existing water treatment facilities for new water reuse options. Using the information from step 5, the quantity and quality of wastewater that is currently reused can be inventoried, and the possibility to identify additional reusers, in case that there is a surplus of treated wastewater not being reused.

In **step 6** actors in the region are identified that produce large quantities of wastewater, and/or require large volumes of water for their activities. These actors are potential sources for water reuse schemes. However, freshwater sources in the region that are currently not used can also be considered as potential sources. For example, the groundwater resources in the case study areas in Argentina and Mexico are currently not used because the water is either polluted or saline. In The Netherlands for example technologies are being developed to reduce the salinity of water in soil and groundwater in situ (e.g. Freshmaker[1]).

Large wastewater producers and water consumers offer the largest potential for matching surpluses of wastewater generated to unmet water demands in a region. In a subsequent stage unmet demands from smaller users can be considered. A spreadsheet with the compiled information on wastewater producers and potential reusers is used to calculate wastewater flows that are currently not reused in the region. The water demands from users in the region listed in the spreadsheet allow to find matches with the surplus available wastewater from producers. An example is shown for the case study area in Argentina in Table 2. In the identification of potential reusers for an available surplus of wastewater, several questions should be answered:

[1] http://www.kwrwater.nl/Freshmaker_vervangt_zout_water_door_zoet_water/

- How large is the disparity between the quality class of the wastewater available and the required quality for the intended reuse? The larger the disparity, the higher the costs of treatment in the water reuse scheme to design.
- Is the potential water reuse of a type that is permitted in the region according to water reuse standards, and is it supported by the regional community where the water reuse scheme would be proposed?
- Is the potential reuser likely to be able and willing to pay for treated wastewater? In regions where abstraction of fresh water is at low cost, this might not be the case.
- How far is the potential reuser located from the wastewater producer? If this is at a large distance, costs for new infrastructure, pumping and transport may become considerable.
- Can existing infrastructure be used for the transport of wastewater and treated water? If so, these offer the potential to save costs on new infrastructure for new WR&R schemes.

Table 2. Example of information used in step 6: wastewater generators and potential re-users in the Suquía River Basin.

Ww producer	Quantity available for reuse (m3/s)	Quality effluent	Potential reuser	Activity	Quality effluent required (minimum)	Water demand (m3/s)	Distance from ww generator (km)
Bajo Grande WWTP	2.7	B	Urban/ Domestic	- Garden/landscape irrigation - Recreational areas, fountains and ponds - Fire protection - Street cleaning	D	0.07 (GW) 6.93 (SW)	1.5 - 12
			Agriculture	- Restricted irrigation (north area) *	C	0.132 (GW) 2.37 (SW)	1.3 - 10
Small WWTPs in upper Suquía River Basin	1.4E-01[1]	-	Urban/ Domestic	- Garden/landscape irrigation - Recreational areas, fountains and ponds - Fire protection - Street cleaning	-	0.67 (SW+GW)[2]	<5

* South area is initially not considered due to long distance between producer and reuser (6-17 kms)
[1] summed quantity of available treated wastewater for 8 small WWTPs, based on population numbers, 50% coverage by sewerage and treatment, and the average wastewater production per inhabitant as derived for the City of Cordoba. Data from the University of Cordoba.
[2] based on population density and current withdrawal per inhabitant in Cordoba City

The final step (7) is the sketching of potential WR&R schemes in a map, connecting wastewater producers and potential reusers identified in the previous step, and collecting information on the characteristics of wastewater discharge and water use by these actors in attribute tables. Such maps can be used in round table sessions for planning water reuse schemes with stakeholders.

5.3 Potential WR&R schemes in the case study areas

The potential WR&R schemes resulting from the application of Modules 4 and 5 from the WP4-tool to the COROADO case study areas are summarized below. For a detailed description of the application of the Modules to each of the case study area we refer to the reports in Annex 1.11.

5.3.1 Potential WR&R schemes in Argentina

In the Suquía River Basin, WR&R schemes have the potential to increase water availability, particularly from groundwater resources. The groundwater in the study site is polluted by effluents from septic tanks and absorption tanks in residential areas which are not served by the central water treatment facilities. However, though the groundwater in the metropolitan area of Córdoba city is polluted, the degree of pollution decreases rapidly outside the city limits. For example, in the northern irrigated area, groundwater extracted in a farm (coordinates: -31.360911,-64.130963) for irrigation purposes was tested for quality. The results showed that it was suitable for consumption (Santiago Reyna, pers. comm.). Arsenic is a major problem in the south east region of the province, but not a concern in the study site. Detected arsenic sources are not inside the limit of the basin.

The implementation of WR&R projects would indirectly decrease surface water pollution, but only if assisted by additional water treatment facilities and/or improved maintenance of legislation on discharge of industrial effluents (Del 4.1).

According to information from Del 2.1, it would be more advantageous to implement WR&R schemes for high water demand users. However, smaller consumers have also been considered for potential WR&R schemes along this study site. Furthermore, potential final users located in the proximity of wastewater producers would present higher options for a feasible reuse, due to decreased costs of water transport (e.g. infrastructure required). Besides distance from supply to demand locations, both quantity and quality of treated wastewater generated and water demanded have been considered.

There is a significant volume of treated wastewater which is available for further reuse. The quantity of discharged effluents from the Bajo Grande WWTP (i.e. 2.7 m3/s) is especially interesting when considering the water demand from potential users, requesting smaller volumes than treated wastewater available. Therefore, according to Del 4.1., the effluents from this WWTP should be investigated for potential reclamation and reuse schemes. However, there is a substantial disparity in terms of water quality, since treated wastewater quality is quite low compared with the one requested from potential re-users. These characteristics could be translated into a high availability of effluents to be reused, but not without further treatment in order to obtain an improved water quality.

According to stakeholders' perception, WR&R schemes considering urban and agriculture water use activities hold the highest potential (stakeholder questionnaire report, Del 8.1). Regarding urban/domestic reuse, the increasing population growth and tourism sector will increase the water demand from this sector, leaving insufficient water for potable water supply to urban areas. Therefore there is potential in reusing treated wastewater for urban/domestic activities such as garden/landscape irrigation, fire protection, toilet flushing and street cleaning, in that order. Wastewater from the five small WWTPs in the villages upstream of the San Roque Reservoir could be reused for these purposes in the same villages.

Other recreational activities such as maintaining water level of ponds and fountains are recommended. Also, the water quality of the San Roque reservoir could be improved by indirect reuse through the implementation of water reuse schemes, with effluents discharged to the reservoir. This would benefit the tourism sector.

As for irrigated agriculture reuse, the use of treated effluents for irrigation of crops not consumed raw (i.e. restricted irrigation) would significantly reduce the use of drinking water for agricultural purpose, increasing the availability for potable water consumption in urban zones (COROADO plenary meeting Córdoba, 2013). Therefore, irrigation of crops such as maize and wheat with reclaimed water is suggested (Del 4.1).

Considering the information described along the present analysis, the following WR&R scheme is suggested:

- WR&R scheme #2: after upgrading the treated wastewater quality with further treatment, effluents from Bajo Grande WWTP and from two other, smaller WWTPs in the northern part of the city are reused in the City of Córdoba for urban/domestic and recreational activities, and for irrigated agriculture of the northern irrigation zone (the southern area has not been considered due to longer distance to be covered).

Figure 3 illustrates the proposed WR&R scheme #2. For a better visualization of the potential scheme, red lines on the map represents possible pipe lines connecting the WWTP to final re-users. Green areas shown in the city of Córdoba which are connected to pipe lines represent parks and recreational areas. Yet, the economic viability of the water reuse application for irrigation in the zone north of Cordoba is questionable. This is because the green belts (irrigated areas) either north and south of the city are shrinking due to land use change. Farms are being turned into suburban housings and industrial premises. Many producers are migrating to eastern areas (5 to 20 km to the east), especially to the northern outskirts of the towns of Montecristo and Malvinas Argentinas.

The University of Cordoba's team in the COROADO project would like to propose an alternative scheme of reused water distribution to the east, where the horticultural industry seems to establish. Topography descends to the east, which reduces frictions and costs of pumping the water. Added to this, taking into consideration the costs of developing a distribution system and the lifetime expected of the service, placing the distribution away from the region that is being progressively engulfed by the urban growth could be a rational thing to do (Santiago Reyna, pers. comm.).

Based on this information, WR&R scheme #3 is proposed, in which treated wastewater from the Bajo Grande WWTP is reused in irrigated horticulture east of the City of Córdoba. The water demand from the new irrigated area is estimated based on .

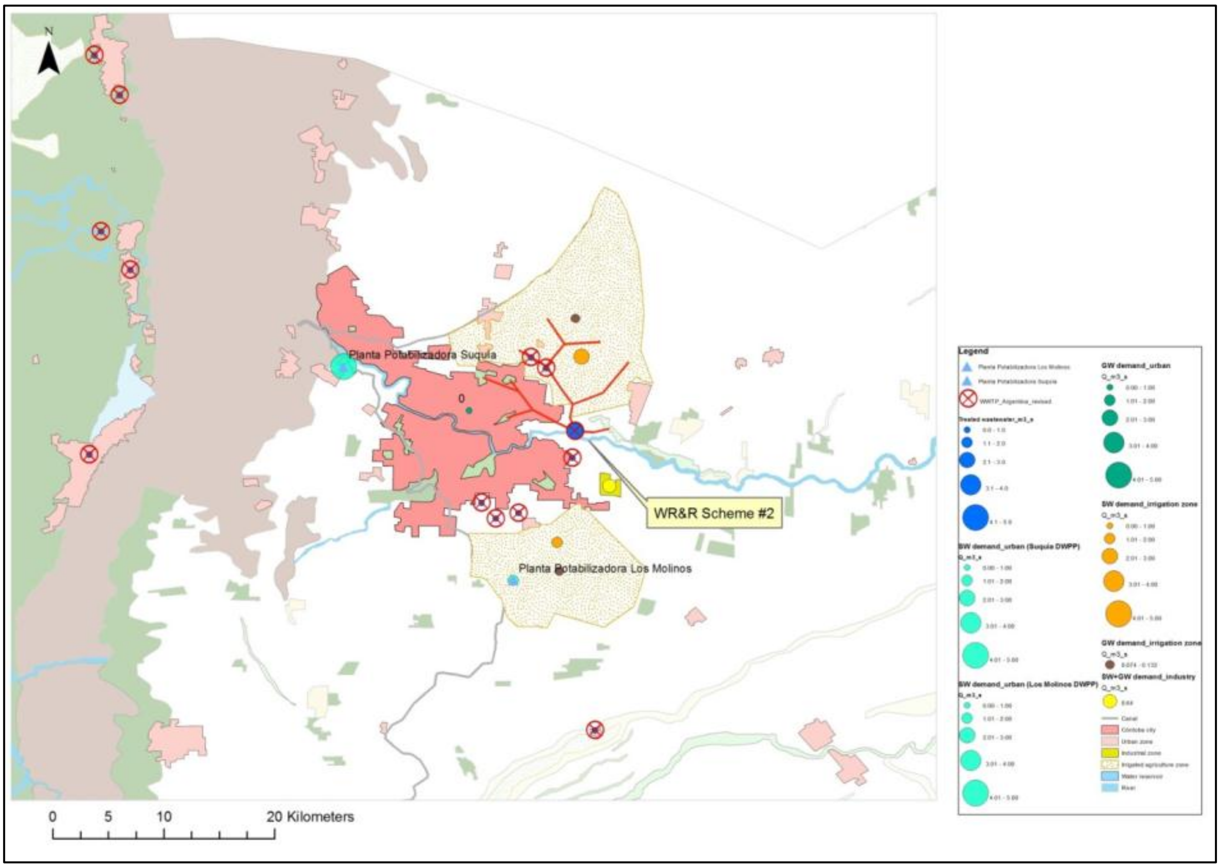


Figure 3. Potential WR&R Scheme #2 in Argentina.

Discussion and conclusions
An overview of the surface and groundwater demand, wastewater generation and reuse per sector in the Suquía River Basin is given in Table 7.

Table 7. Overview of quantity of wastewater production (collected and treated) and water demand in the Suquía River Basin

SECTOR	Urban/domestic	Industrial	Agricultural	TOTAL
Surface water demand (m3/s)	6.93[1]	0.45	3.22	**10.6**
Groundwater demand (m3/s)	0.07	0.16	0.17	**0.4**
Wastewater production (m3/s)	2.84[2]	-	0.27 (northern zone) 0.10 (southern zone)[3]	**3.2**
Wastewater reused (m3/s)	-	0.03	-	**0.03**

[1] excluding water demand from the villages in the upper part of the river basin, since quantities are unknown
[2] including wastewater produced by the villages in the upper part of the river basin (estimated)
[3] rough estimation based on model simulations of average water flow available in spring and summer (2000-2010). Not included in this analysis.

Considering the current analysis, the implementation of WR&R schemes in the Suquía River Basin presents a great potential. Water reclamation and reuse is becoming more and more interesting in this area, because the options to bring more water to the basin are very expensive. A large volume of effluents (i.e. 3.2 m3/s on average) are daily discharged from the Bajo Grande WWTP and other WWTPs without any direct reuse and benefit obtained. However, a limiting factor corresponding to water quality has been identified, hindering the implementation of any reuse project in the study site. Therefore, an increase of the capacity of the Bajo Grande WWTP and/or the upgrade of treatment technologies to obtain better quality from effluents (i.e. C and D quality class) is highly recommended.

Likewise, a higher percentage of wastewater collected and treated in the Suquía River Basin (currently only 33%) would significantly increase the availability of effluents for future reuse projects as well as their quality for reuse. Increasing control of illegal wastewater discharge from industries and other establishments would play a determinant role in improving wastewater quality.

As for the supply side, reduction of pressure on the drinking water supply, and repair of leakages, could lead to a significant reduction in gross water withdrawal. Therefore, a combined approach of increasing the capacity of the municipal WWTP or the technologies applied in combination with WR&R schemes may be an option to increase water quality in the river basin and improve water availability, and therefore to gain benefits from direct reuse. The collection of agricultural drainage water (estimated at 11% of the blue water demand for agriculture) would also increase the volume of wastewater available, therefore this option must be further explored.

Finally, for a better approximation of the wastewater generated which could be potentially reused by different water consumers, further analysis on other aspects such as transport and storage facilities, land elevation difference between wastewater producers and potential reusers), costs of upgrading water quality versus costs of retrieving existing fresh water sources, water quality required for specific activities, willingness to pay, etc. should be undertaken.

5.3.2 Potential WR&R schemes in Brazil

According information extracted from COROADO Del. 2.1., it would be more advantageous to implement WR&R schemes for high water demand users in the case study area in Brazil. However, smaller consumers have been also considered here for potential WR&R schemes. Furthermore, those actors located in the proximity of wastewater producers would present higher options for a feasible reuse due to decreased costs of water transport (e.g. infrastructure required).

Even though there is a disparity in effluents quality from producers to consumers, it can be observed (in terms of quantity generated) that a large number of industries demanding water could be supplied by treated wastewater from different producers. Making this possible could free up blue water resources that are currently extracted from surface and groundwater for use by these industries. However, the distance from producer to consumer as well as the different water quality (if not upgraded) could present a problem for further reuse.

Other re-users besides industries are also considered. A large number of wastewater producers are spread around the SPMR and therefore located next to urban areas. As a result, urban reuse must be always an alternative to take into account, but also considering the quality required.

The potential of wastewater reuse in irrigated agriculture is low, due to the long distance between WWTPs and irrigated land (COROADO Del. 2.1 and Figure 5). However, this situation might change when considering the industrial sector as a wastewater producer. Certain industries generating large quantities of wastewater have been located only 2 km far from irrigated land. Therefore, the reuse of wastewater from industries in irrigated agriculture should be further explored.

Figure 5 gives an idea of potential WR&R schemes, matching wastewater producers (i.e. WWTPs and industries) and water consumers (i.e. industries, irrigated agriculture, urban/domestic activities), based on the criteria of quantity and distance already mentioned. Wastewater producers are represented with blue circles, whereas potential re-users are shown with all other colours. Potential pipe lines connecting wastewater producers to potential re-users are represented with red lines. Current pipe lines from existing WR&R schemes (Figure 4) are represented with green lines. Numbers contained in a box refer to specific and potential WR&R schemes, including combinations of wastewater producers and potential re-users.

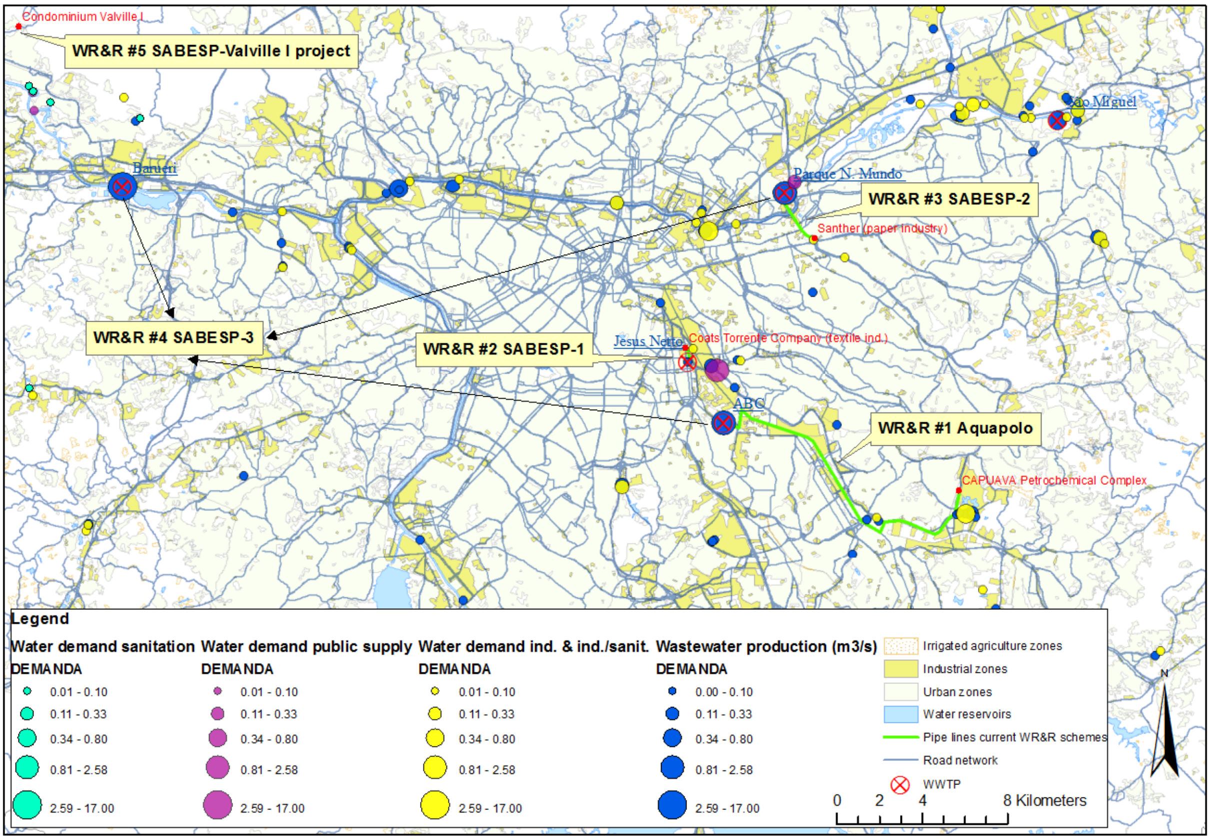


Figure 4. Distribution of current WR&R schemes, including wastewater producers and current water consumers in SPMR, Brazil.

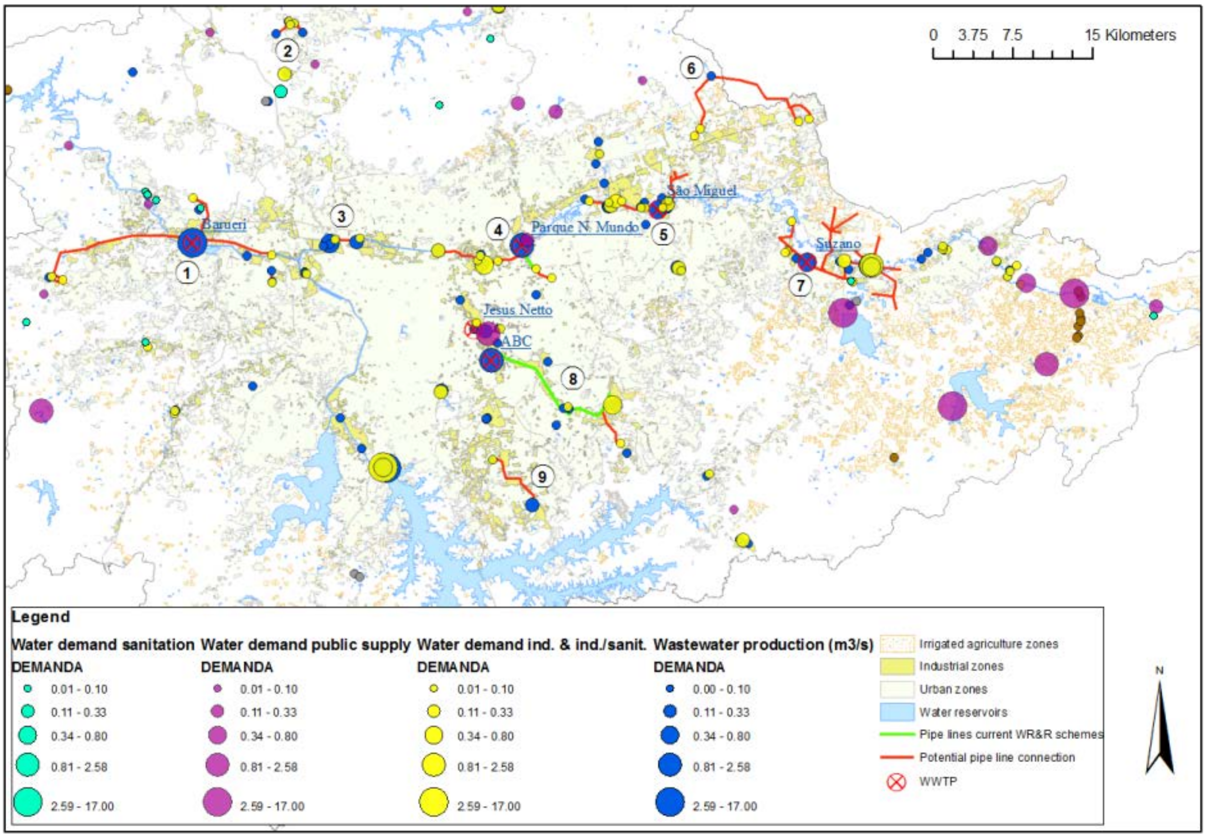


Figure 5. Potential WR&R schemes in the SPMR.

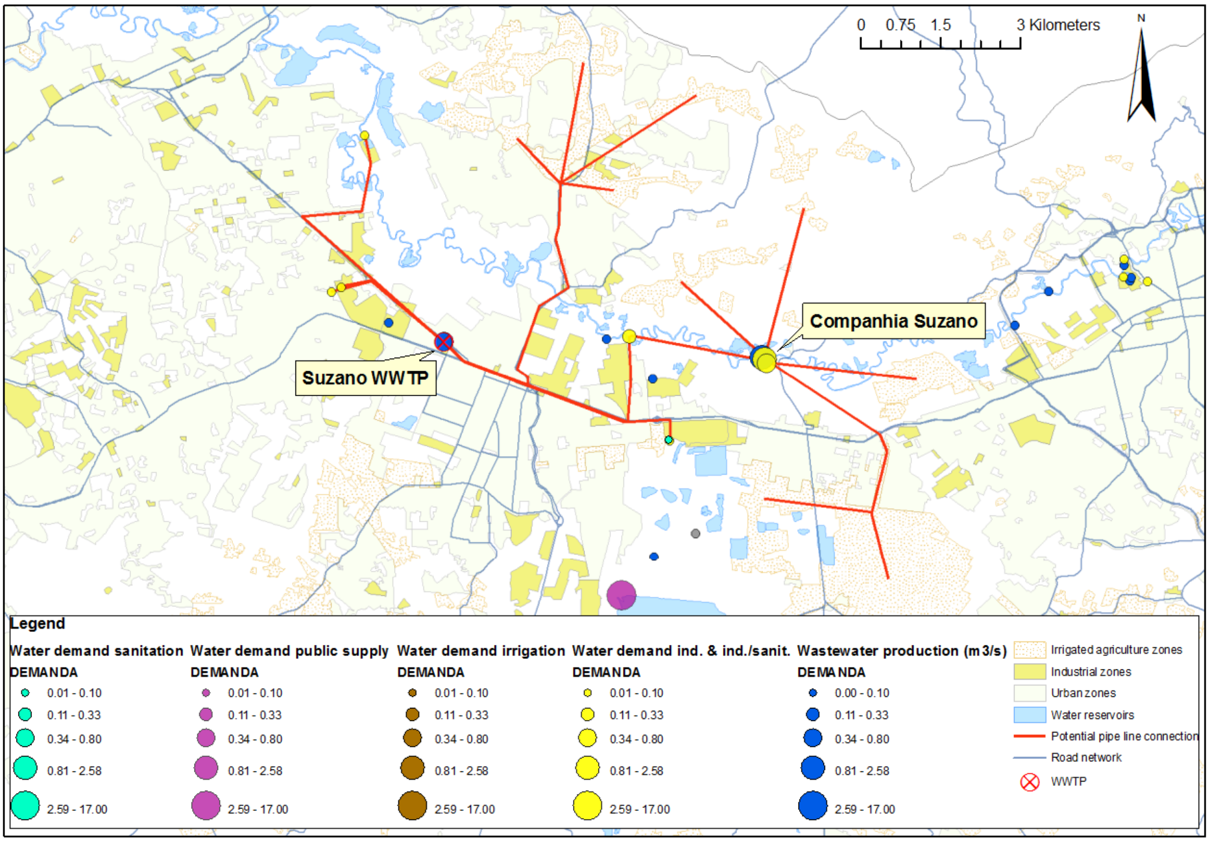


Figure 6. Potential WR&R scheme #7.

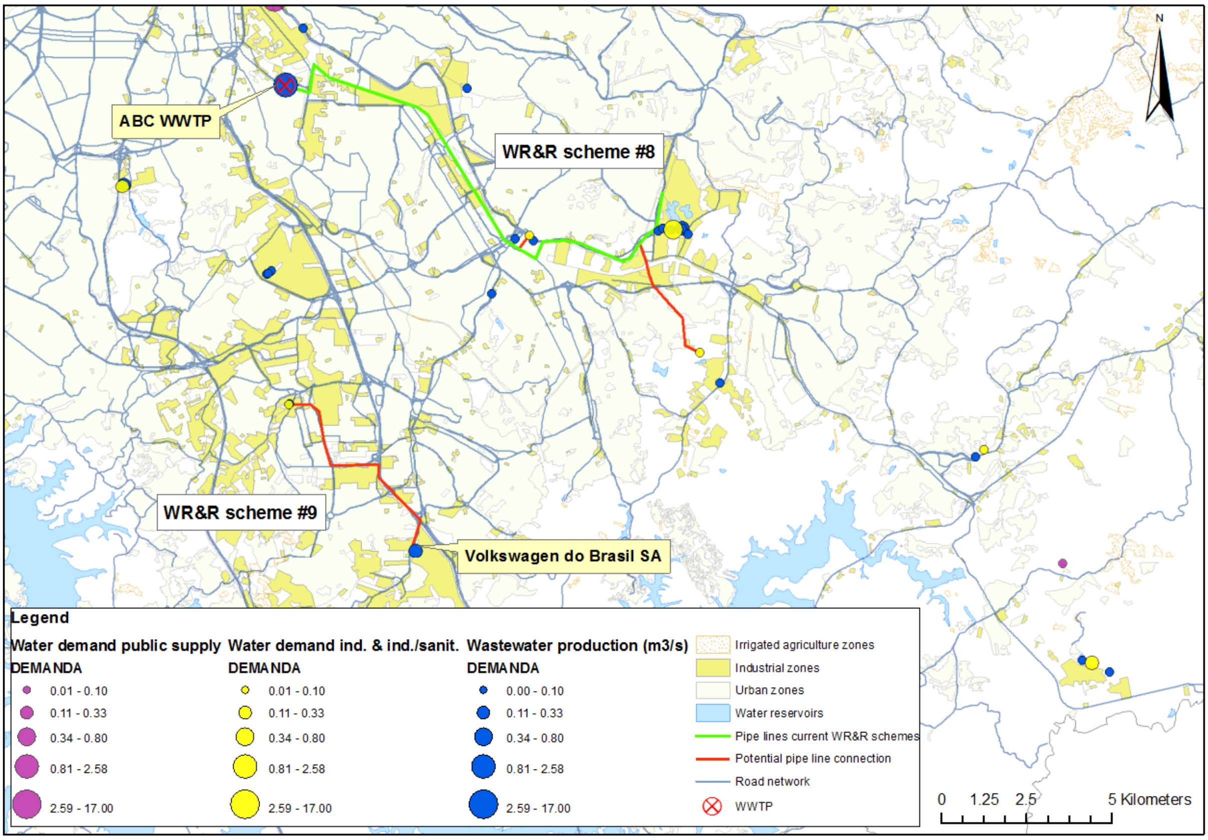


Figure 7. Potential WR&R #8 and #9.

Discussion and conclusions

A global overview of wastewater generated and water (surface and groundwater) demanded per sector in the SPMR is given in Table 3.

Table 3. Overview of quantity (m3/s) of wastewater production and water demand in the SPMR

SECTOR	Urban	Industrial	Agricultural	TOTAL
Wastewater production (m3/s)	15.72	23.35	-	**39.07**
Surface water demand (m3/s)	35.05	23.34	0.6	**59.99**
Groundwater demand (m3/s)	1.08	3.43	0.04	**4.55**

For the urban sector, it is observed that there is a significant amount of water which is not collected and further treated, since water supply and wastewater discharged quantities do not match. Regarding the industrial sector, the amount of water demanded and the wastewater generated have similar values, corresponding to a better collection system. As for agricultural use, there is no data about wastewater collected and treated, therefore only water demand for irrigation is considered.

After identifying the largest wastewater producers and potential final reusers, several WR&R schemes have been suggested. Considering the total water demand from the potential industrial reusers which could be supplied by different wastewater generators, a number of 3.08 m3/s is obtained. This figure does not consider potential urban/domestic and irrigation reuse, only industrial reuse. This is especially important when comparing this number with the groundwater demand in the SPMR (4.55 m3/s). In other words, a complete reuse of wastewater from the selected producers by the suggested consumers would mean that hardly any groundwater resources would be needed anymore to cope with global water demand.

However, for a better approximation of the wastewater generated which could be potentially reused by different water consumers, further analysis on other aspects such as transport and storage facilities, costs of upgrading water quality versus costs of retrieving existing fresh water sources, water quality required for specific activities, willingness to pay, etc. should be undertaken.

5.3.3 Potential WR&R schemes in Chile

In the Copiapó River Basin, groundwater depletion is an important driver for water scarcity and stress. Therefore any WR&R solution could be helpful that could either free up water, reducing the need to extract from groundwater, or that could re-inject treated wastewater into the groundwater.

According to information from COROADO Del. 2.1, it would be more advantageous to implement WR&R schemes for high water demand users. However, smaller consumers have also been considered for potential WR&R schemes along this study site. Furthermore, potential final users located in the proximity of wastewater producers would present higher options for feasible reuse, due to decreased costs of water transport (e.g. infrastructure required).

Besides distance from supply to demand locations, both quantity and quality of treated wastewater generated and water demanded have been considered. The volume of treated wastewater available for water reuse is very limited when compared to water demand from potential and suggested re-users. However, such a disparity in terms of quantity does not occur regarding water quality. This could be translated into numerous but small WR&R schemes where reduced volumes of treated wastewater would be reused by different sectors demanding a similar water quality.

Urban/domestic reuse is pointed out as the main potential beneficiary from potential WR&R schemes in the study site, mainly because of the large volume of water consumed within the Copiapó city and the stakeholders' positive perception (Del 2.1). However, Chilean legislation is still quite unclear regarding urban reuse. Therefore the reuse of reclaimed water for some urban activities such as irrigation of gardens and recreational areas, street washing, etc. are suggested as a starting point. Due to the suitable location of the Copiapó WWTP, in the vicinity of the urban zone, this is the wastewater generator proposed to supply with surplus treated wastewater to the City of Copiapó.

Regarding the industrial sector, mining activities are expected to grow, with 33 new mining projects upcoming up till 2020. Therefore a larger volume of water will be required to supply such future activities. Currently, a great number of groundwater extraction points supplying mining activities are located in the proximity of the Tierra Amarilla WWTP. Therefore, this municipal treatment plant is suggested to supply the increasing mining sector with the surplus of treated effluents. This is current practice.

Despite the high potential to reuse wastewater in irrigated agriculture, less than 4% of the agricultural water demand is covered by reused water. Although municipal treated wastewater is available in just a small proportion, there is still potential to reuse these effluents in a more controlled way. Currently, effluents which are not sold to the mining industry are discharged into the river and reused by farmers downstream. It is suggested to reuse treated wastewater from Tierra Amarilla WWTP in agriculture, especially in the Sector 4 which relies on surface water for irrigation. Copiapó WWTP is also proposed to further develop WR&R schemes including a formal and direct reuse of treated effluents in the Sector 5, where crops are irrigated with extracted groundwater. This would help to partially eliminate the need to withdraw groundwater from the aquifer in Sector 5.

Considering the information described along the present analysis of the Copiapó River Basin, the following two WR&R schemes are suggested for each municipal WWTP:

- WR&R scheme #3: surplus treated wastewater from Copiapó WWTP is reused in the urban and agriculture sector, considering the characteristics described before.
- WR&R scheme #4: surplus treated wastewater from Tierra Amarilla WWTP is reused in mining activities and agriculture sector relying on surface water sources.

Figure 8 and Figure 9 illustrate WR&R #3 and #4, respectively. For a better visualization of the potential schemes, red lines on the maps represent possible pipe lines connecting WWTPs to final re-users.

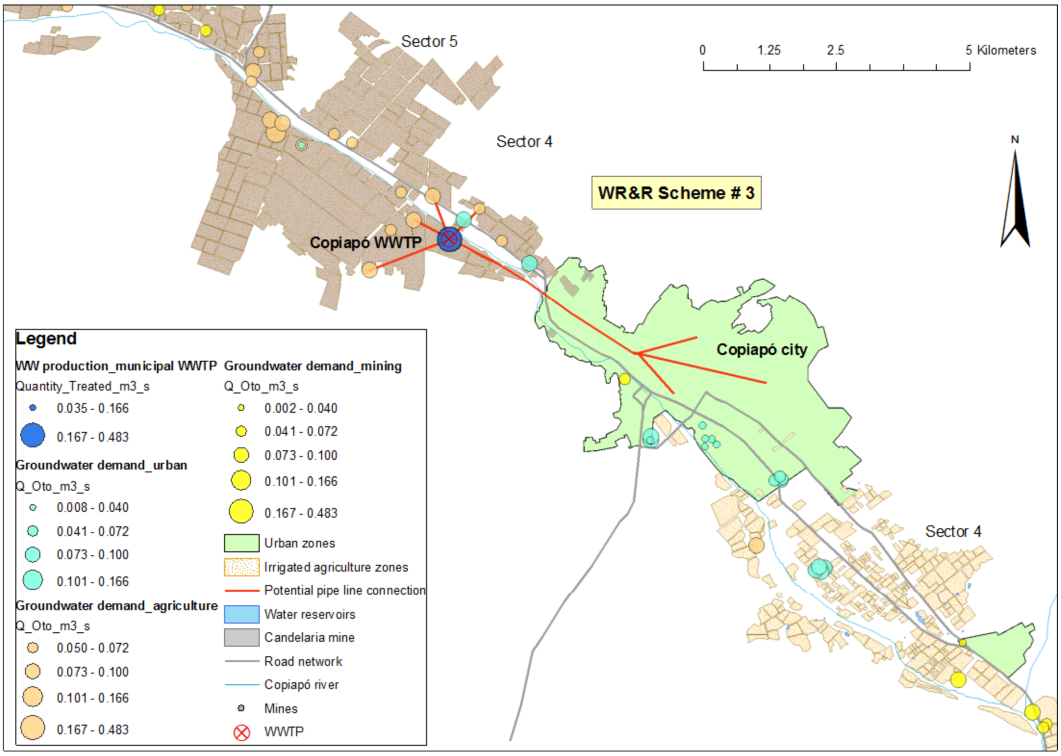


Figure 8 Potential WR&R Scheme #3 for Copiapó River Basin.

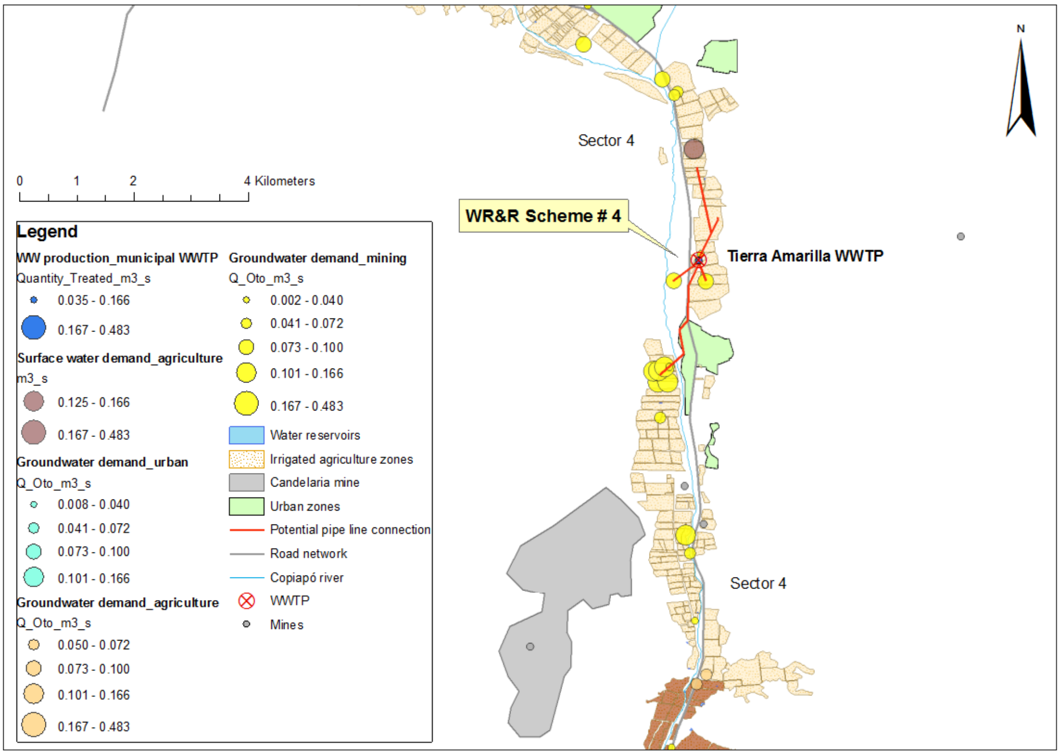


Figure 9 Potential WR&R Scheme #4 for Copiapó River Basin.

Discussion and conclusions

An overview of the surface and groundwater demand, wastewater generation and reuse per sector in Copiapó River Basin is given in Table 4. It is important to mention that some information sources consulted for this application provide with data from different years (e.g. DICTUC 2008, DICTUC 2010, etc.) so that different figures regarding water volumes were obtained.

Table 4 Overview of quantity of wastewater production and water demand in the Copiapó River Basin

SECTOR	Urban/domestic	Industrial	Agricultural	TOTAL
Surface water demand (m3/s)	-	-	1.5	**1.5**
Groundwater demand (m3/s)	1.38	2.0	7.9	**11.68**
Wastewater production (m3/s)	0.36	-	-	**0.36**
Wastewater reused (m3/s)	-	0.16	0.06	**0.22**

Considering the current analysis, even though there is a large potential for reuse in all considered sectors, the reduced generation of wastewater hinders the design and implementation of new future WR&R projects. Moreover, due to environmental concerns, WWTPs must discharge into the river at least 0.1 m3/s of treated wastewater (Christian Hunter, pers. comm.). This specific issue also limits the amount of available treated effluents for direct reuse.

However, a recommendation to increase the availability of wastewater for potential WR&R schemes would include the collection of agricultural drainage water, which would imply an important water source for irrigation purposes, especially downstream.

Although it was not mentioned in the report, the use of salt water from the ocean to supply water demand from urban and mining activities is already implemented. The use of seawater for non-potable urban and industrial purposes by desalination seems the most promising alternative for freshwater supply, and another desalination plant is planned to supply urban areas and the mining industry. The reasons for not having included such reuse schemes in this report lies on the specific focus of the current analysis on wastewater reuse.

Finally, for a better approximation of the wastewater generated which could be potentially reused by different water consumers, further analysis on other aspects such as transport and storage facilities, land elevation difference (between wastewater producers and potential reusers), costs of upgrading water quality versus costs of retrieving existing fresh water sources, water quality required for specific activities, willingness to pay, etc. should be undertaken.

5.3.4 Potential WR&R schemes in Mexico

According to information extracted from COROADO Del. 2.1, it would be more advantageous to implement WR&R schemes for high water demand users in the Rio Bravo/Grande Lower Basin. However, smaller consumers have also been considered for potential WR&R schemes along this study site. Furthermore, potential final users located in the proximity of wastewater producers would present higher options for feasible reuse, due to decreased costs of water transport (e.g. infrastructure required).

Besides distance from supply to demand location, both quantity and quality of treated wastewater generated and water demanded have been considered. The majority of wastewater producers in this area generate smaller volumes than corresponding and suggested re-users. This applies particularly to potential agricultural re-users. However, such a disparity in terms of quantity does not occur regarding water quality. This could be translated into numerous but small WR&R schemes where reduced volumes of treated wastewater can be reused by different sector demanding a similar water quality. The implementation of WR&R schemes including municipal WWTPS is highly recommended.

Agriculture is pointed out as the main potential beneficiary from WR&R schemes, due to the large water demand required and the central distribution of irrigated land in the Río Bravo Lower Basin. Moreover, it would not require a large infrastructure since irrigated land is, especially in some sectors of District 025, located less than 1 km far from the nearest wastewater producer, meaning a lower cost.

Besides agriculture, urban and industrial sectors hold certain potential for reuse of reclaimed water. A designed infrastructure consisting in pipe lines could provide with specific connections between WWTPs and urban/industrial users. Considering the information described along the present analysis of the Río Bravo/Grande Lower Basin, the following WR&R schemes are suggested (Del. 2.1):

- WR&R scheme #5: this scheme is already planned, involving the Río Bravo WWTP and an iron and steel industry located 5 km far from the municipality of Rio Bravo. A volume of 0.07 m3/s of treated wastewater will be transported from the WWTP to the facilities of the industry for final reuse.
- WR&R scheme #6: the Thermoelectric plant in Río Bravo plays an important role as this is the industry consuming the largest amount of surface water (0.159 m3/s) in the study site. The municipal WWTP located in Río Bravo could supply treated effluents to partially fulfil the requirements from the thermoelectric plant. If needed, the Reynosa WWTP 1 and 2 could supply the rest of volume needed, although it would involve a greater infrastructure. Wastewater from the Thermoelectrical plant should also be considered for urban reuse, for instance. Note that a potential agricultural reuse would be also possible.
- WR&R scheme #7: the industry Química Fluor Matamoros demands (0.048 m3/s), which could be supplied by Matamoros East WWTP, supplying 0.385 m3/s.

Figure 10 and Figure 11 illustrate WR&R schemes #6 and #7, respectively. For a better visualization of the potential schemes, red lines on the maps represent possible pipe lines connecting wastewater producers to final re-users.

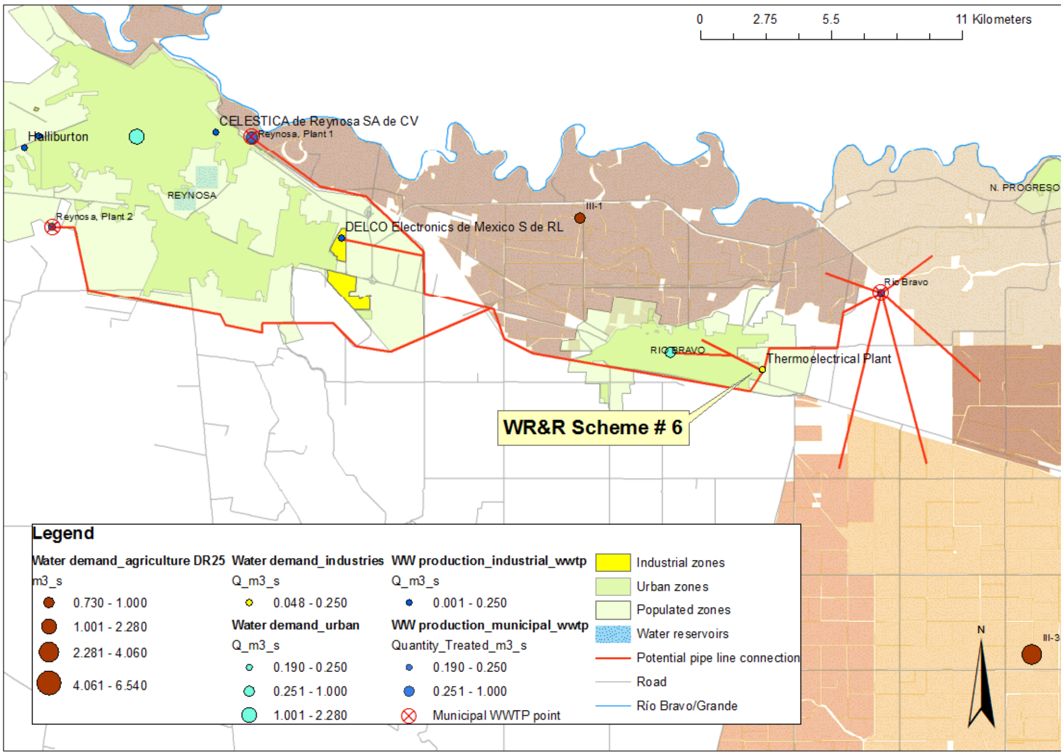


Figure 10 Potential WR&R scheme #6 for the Rio Bravo/Grande Lower Basin.

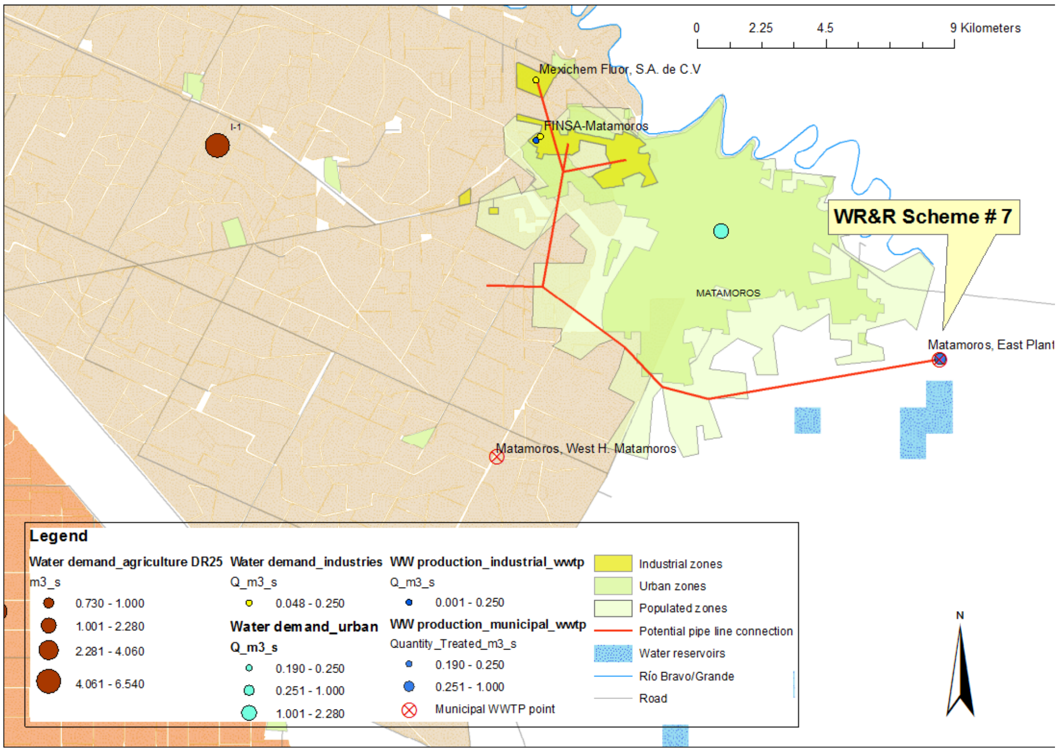


Figure 11 Potential WR&R scheme #7 for the Rio Bravo/Grande Lower Basin.

Discussion and conclusions

An overview of surface water demand, wastewater generation and reuse per sector in the Rio Bravo/Grande Lower River Basin is given in Table 5. It is important to mention that very limited information was available with regard to industrial wastewater generation. Moreover, figures regarding wastewater reuse only consider current and primary WR&R schemes, where volumes are available. Therefore there is an assumption that the total volume for wastewater production and reuse might be slightly higher. Urban and industrial wastewater reused are combined, since no specification is made in the current reuse schemes. Nevertheless, it is assumed that there is no wastewater reused within the industrial processes, and the major percentage is reused in urban activities.

Table 5. Overview of quantity (m3/s) of wastewater production and water demand in the Río Bravo/Grande Lower Basin

SECTOR	Urban	Industrial	Agricultural	TOTAL
Surface water demand (m3/s)	5	0.25	28.19	**32.87**
Wastewater production (m3/s)	1.84	0.14	-	**1.98**
Wastewater reused (m3/s)	0.00055			**0.00055**

Considering the current analysis, it is clear that the Río Bravo/Grande Lower Basin has a significant potential for WR&R schemes. An important volume of wastewater is not being reused at the moment, even though a large number of treated effluents from different generators show a water quality suitable for reuse. Specially it is advisable to take wastewater generated from municipal WWTPs into account. As for agricultural reuse, non-food crops hold the highest potential for reclaimed water reuse, due to lower water quality requirements for irrigation.

Regarding urban reuse, the municipalities of Reynosa and Matamoros include important recreational areas and ponds, as well as golf courses, now irrigated with first-use water that could use reclaimed waters (Del. 2.1.). Therefore the use of treated effluents from municipal WWTPs is highly recommended to fulfil the water requirements from these urban activities.

The industrial sector, although demanding the smallest percentage of surface water in the study site, must search for water suppliers if an increasing development is intended. Therefore the use of reclaimed water is presented as an alternative and available water source in the area.

However, for a better approximation of the wastewater generated which could be potentially reused by different water consumers, further analysis on other aspects such as transport and storage facilities, land elevation difference (between wastewater producers and potential reusers), costs of upgrading water quality versus costs of retrieving existing fresh water sources, water quality required for specific activities, willingness to pay, etc. should be undertaken.

Finally, some recommendations to increase the availability of wastewater for potential WR&R schemes could be considered. First, a higher percentage of municipal wastewater treated after collection should be achieved (currently it is only 48%); and second, the collection of agricultural drainage water (especially from district 025) would mean an important water source for irrigation purposes, especially down-stream. Both are two important factors to be further explored.

5.4 References

Krovvidy, S. (1998). Intelligent Tools for Wastewater Treatment Design. *Computer-Aided Civil and Infrastructure Engineering*, *13*(3), 219–226. doi:10.1111/0885-9507.00100

McDlelland, C. J. (2011). *Identifying key factors that contribute to water reuse feasibility using a hybridized decision and scenario tool*.

Ullmer, C., Kunde, N., Lassahn, A., Gruhn, G., & Schulz, K. (2005). WADO™: water design optimization—methodology and software for the synthesis of process water systems. *Journal of Cleaner Production*, *13*(5), 485–494. doi:10.1016/j.jclepro.2003.09.009

Wintgens, T., & Hochstrat, R. (2006). *Integrated Concepts for Reuse of Upgraded Wastewater*. (T. Wintgens & R. Hochstrat, Eds.) (pp. 1–184). Aquarec.

Evaluation of Waste Water and Water Reuse options

Contribution of FHNW to Deliverable 4.2

Contents

Accronyms and definitions

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
FC	Faecal Coliform
MLSS	Mixed Liquor Suspended Solids
NTU	Nephelometric Turbidity Units
TC	Total Coliforms
TSS	Total Suspended Solids
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphate
TSS	Total Suspended Solids
WHO	World Health Organization
WWTP	Wastewater Treatment Plant
Headloss	In fluid mechanics, the drop in the sum of pressure head, velocity head, and potential head between two points along the path of a flowing fluid, due to causes such as fluid friction. Used to calculate the required pumping head in distribution pipes
US-EPA	United States Environmental Protection Agency
Capex	Capital expenditures, capital costs based on the construction costs
Opex	Operational expenditures
Wastewater	Water which has been polluted by human activities
Greywater	Wastewater from domestic activities (bathing, cleaning, laundry etc.)
Blackwater	Wastewater which contains urine and faeces
Wastewater treatment	Improvement of water quality by applying a number of methods/technologies

Primary treatment	Usually first step in the cleaning process involving removal of solids, oils and greases by flotation, sedimentation and screening
Secondary treatment	Removal of dissolved and suspended biological matter, which typically involves biological processes by microorganisms (activated sludge, membrane bioreactors etc.
Tertiary treatment	Cleaning to a high level of purity or/and removal of specific contaminants (e.g. heavy metals) and can include disinfection
Effluent	Water flow after (primary, secondary or tertiary) treatment
Water reuse	Beneficial use of treated wastewater
Water reclamation	Cleaning of wastewater to a purity that can be used for specific purposes
Direct reuse	Direct use of reclaimed water for a specific purpose
Indirect reuse	Reuse of wastewater which has been previously mixed and diluted with fresh water by discharge into receiving water bodies

1 Selection and evaluation of Wastewater and Water Reuse options

1.1 Importance and objectives of Water Reuse

When having a holistic look at the water cycle of countries or regions facing water scarcity, it seems that water abstraction is beyond the sustainable level, often more important than the water recharge, therefore diminishing water availability to dramatic levels. Water reuse is one of the most promising integrated solutions to improve access to water and can be an alternative to abstracting new water sources as it performs two fundamental functions (Urkiaga et al., 2006a; Wintgens & Hochstrat, 2006):

- Treated wastewater can be reused as a water resource for beneficial purposes
- Wastewater is kept out of receiving environments thus reducing pollution

These two fundamental functions appear to be the primary incentives for implementing water reuse schemes (D. Bixio et al., 2006). This also applies to the COROADO case study sites, where the need for additional freshwater resources is the main driver for the interest in WR&R schemes, also because WR&R schemes are considered more cost-effective than alternative solutions to obtain additional freshwater resources (new freshwater resources are often located at an important distance and require high pumping and distribution costs). Environmental protection, corresponding to the second fundamental function of water reuse, is mentioned as the second most important driver for the interest in WR&R in the Lower Río Bravo/Grande river basin (Mexico) and the São Paulo Metropolitan Region (Brazil). (Assimacopoulos et al., 2012[1], and results from the stakeholder workshops in Porto et al., 2012[2]) The United Nations, in their world water development report 2014, also state that future water and energy consumption of a new or an expanding city can be reduced during the early stages of urban planning through the development of compact settlements and investment in systems for integrated urban water management, such as the use of multiple water sources – including wastewater reuse – and the treatment of water to the quality needed for its use rather than treating all water to a potable standard." (WWDR 2014)

The objective of wastewater recycling and reuse is the treatment of wastewater to a stage of purity that can directly be used for specific purposes. Water reuse has received growing attention with regard to mitigation of water scarcity and as an opportunity to avoid high first-use water prices. Wastewater reuse can be classified as direct or indirect reuse, as shown in Figure 1.

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[1] Assimacopoulos, D., Manoli, E., Katsiardi, I., & Stathatou, P. (2012). *Workshop synthesis report: Stakeholder perceptions regarding water recycling and reuse applications in the COROADO study sites - Coroado internal report* (p. 134).

[2] Porto, M. F. A., Dalcanale, F., Mierzwa, J. C., Rodrigues, L. di B., Pio, A., Gironás, J., Dorsaz, J.-M., et al. (Eds.). (2012). *Report on the Context of the Areas, Workshop Structure, and Development. Coroado Deliverable 2.1*. *Coroado* (p. 206). Coroado.

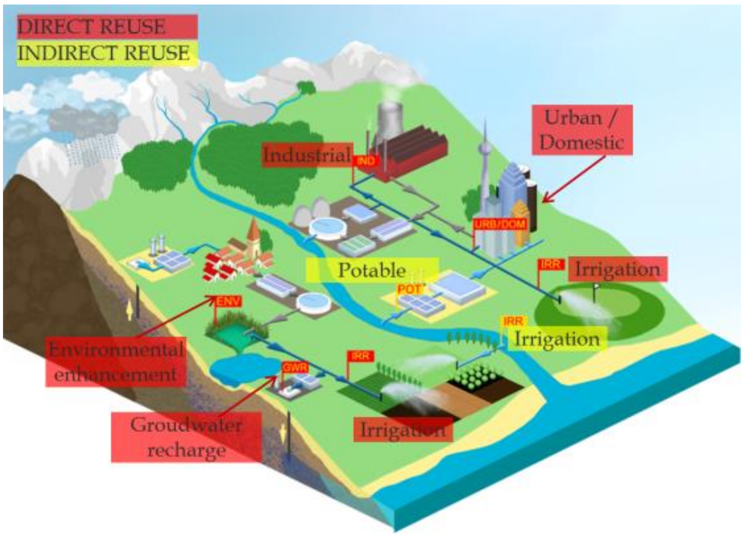

Figure 1: The anthropogenic water cycle with direct and indirect reuse (Wintgens et al., 2006)

Direct reuse refers to the direct use of reclaimed water for a specific purpose. Direct water reuse can supply applications (Figure 1) such as agricultural irrigation (IRR), industrial uses such as cooling and process water (IND), urban and recreational uses such as garden irrigation and street washing (URB), groundwater recharge (GWR) and ecological uses (ENV).
Unintentional indirect reuse refers to the use of water downstream of a discharge of (treated or untreated) wastewater into a receiving water body. The effluent from WWTPs is mixed, diluted and further cleaned by naturally occurring chemical and biological processes in the receiving water body, which is the most common practice worldwide.
Intentional indirect reuse is the planned linkage between the discharge of treated wastewater into an environmental water body with further usage (Levine & Asano, 2004). An example of intentional indirect reuse is groundwater (aquifer) recharge of effluents for further reuse. Both for direct and indirect reuse, the specific reuse application (purpose) together with the relevant legislation determine the level of purity which needs to be achieved.

1.2 Challenges and objectives of the evaluation system developed: "stage II assessment"

1.2.1 Definition of water reuse options: unit processes and treatment trains

In order to proceed to the intended type of water reuse, a myriad of widespread technology options are available. Usually only experts from the field of wastewater treatment and sanitary engineering can count on a wide knowledge and understanding of the whole set of technologies and their combinations. The following sections describe a system developed within WP4 of the Coroado project in order to facilitate the selection and evaluation of different options also for non-expert users. There are many water reclamation technologies available for primary, secondary and tertiary treatment, as well as for disinfection. Individual technologies are called unit processes (UP). The unit processes selected in the system are shown in

Table 1 (*Selection based on (Adewumi, 2011a; Joksimović, 2006a) and personal communications with several water reuse experts*). Each unit process is described in details in Appendix II Unit Processes Factsheets (Page 54)

Table 1: List of unit processes considered in the stage II assessment[3]

Primary treatment (P)	**Disinfection (D)**
▪ Bar screen ▪ Coarse screen ▪ Grit Chamber ▪ Equalization Basin ▪ Sedimentation without coagulant ▪ Sedimentation with coagulant ▪ Anaerobic stabilization ponds	▪ Ozonation ▪ Chlorine gas ▪ Chlorine dioxide ▪ Ultraviolet disinfection
Secondary Treatment (S)	**Tertiary Treatment (T)**
▪ Activated sludge ▪ Low Loaded Activated Sludge w/o de-N + Sec Sedim. ▪ Low Loaded Activated Sludge w de-N + sec. Sedim. ▪ High Loaded Activated Sludge + Sec. Sedim. ▪ Extended aeration ▪ Trickling filter with secondary sedimentation ▪ Rotating biological contactor (RBC) ▪ Stabilization ponds: Aerobic ▪ Stabilization ponds: Facultative ▪ Membrane bioreactor (MBR)	▪ Constructed wetland ▪ Enhanced biological phosphorus removal (EBPR) ▪ P-Precipitation ▪ Denitrification ▪ Dual media filter ▪ Microfiltration ▪ Ultrafiltration ▪ Nanofiltration ▪ Reverse osmosis ▪ Activated Carbon ▪ Ion exchange ▪ Advanced oxidation process ▪ Soil-aquifer treatment (SAT) ▪ Maturation pond ▪ Flocculation ▪ Electrodialysis

These unit processes usually work in combination commonly referred to as **Treatment Trains (TT)**. For each identified case study with potential for water reuse, there are plenty of feasible combinations of technologies that can meet the required pollutant removal target at the desired treatment cost. In this chapter, a **water reuse option has to be understood as a feasible treatment train** in order to treat the available wastewater to a quality complying with the intended use. The system developed within the Stage II assessment contains a list of treatment trains with characteristics, such as technical performance on pollutant removals, several evaluation criteria, requirements and impacts, as well as a quantitative cost module to estimate the foreseen costs of treatments. The system calculates which of those treatment trains would comply with the requirements defined by the user and present the best options to the non-expert user based on the different characteristics defined before.

1.2.2 Starting point

The starting point for the evaluation of water reuse options is the end of the "Stage I" assessment from WP4. The following information should be available:

- Available water to be reused (*quality, quantity and location*)
- Intended reuse(s) (*quality and quantity required, location*)
- Community profile composed of several locally-specific information (*e.g. electricity costs, labor cost, water tariff, etc., described in chapter 1.6.4*)

[3] Subject to changes depending on the development of the ongoing system.More information of primary, secondary, tertiary treatment and disinfection in chapter 1.5.

- Several scenarios to be analyzed; for example fictive scenario questions could be:
    1. Given 2,000 m^3/day of wastewater from medium quality at a known location in the city of Cordoba, Argentina, it is envisaged to treat this water in order to reuse it for agriculture of non-food crops. What are the three best options available, what will be the performance of different options and how much will it cost?
    2. It is planned to reclaim the secondary effluent of a wastewater treatment plant (WWTP) treating wastewater of about 5,000 inhabitants and to treat its effluent in Mexico for two potential re-users: one industry that needs water with medium quality 1km away from the WWTP and one fruit producer next to the WWTP that needs good water quality. What are the best options available and what are the foreseen costs of distribution?
    3. In Chile, it is foreseen to pump a new source of freshwater 200 km away from a city of 10,000 people to complement the lack of water availability. On the other hand, it would be feasible to reclaim the wastewater from the city to cover the needs. Which solution would be most cost-efficient? What evaluation criteria could be considered in the choice?

1.2.3 Evaluation of different water reuse options / treatment trains

For each scenario to analyze and based on the input data provided (available wastewater to be reused, intended reuse and several locally-specific characteristics required for the calculation), the system will calculate several parameters:

- **Pollutant removal performance** of every treatment train included in the system (chapter 1.4.2)
- **Lifecycle treatment costs** (chapter 1.6)
- **Evaluation criteria** (chapter 1.7).

Based on that information, the stage II assessment proposes an evaluation algorithm that calculates the 3 best candidates, as presented in Figure 2. Every parameter are calculated for every treatment trains included in the system and three treatment trains that can be defined by the user. The algorithm proposed three different evaluation methodologies to select the three best candidates within the list. The first possibility (1) eliminates all treatment trains that do not comply with the quality requirements (based on the maximal removal performance of each unit process). Then, a ranking is made based on the weights for each single indicator defined by the user. The second possibility (2) first eliminates all treatment trains that do not comply with the required quality and then rank the three options with the lowest lifecycle treatment costs calculated. The user can then evaluate the three options by analyzing the whole set of evaluation criteria calculated. The third possibility (3) is primarily intended for experts and allows a manual selection of the best options based on a subjective evaluation of all evaluation criteria presented. The details of the methodology applied and calculation involved are presented in chapter 1.8.

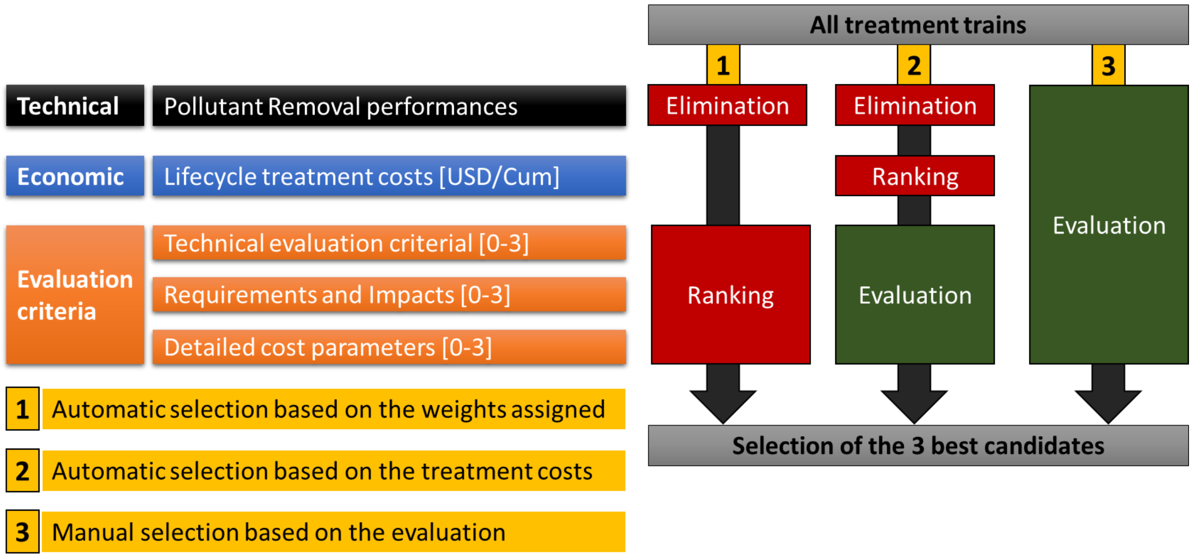

Figure 2: Evaluation algorithm proposed by the stage II assessment.

1.2.4 Objectives and limitations

The main objectives of the stage II assessment is to **promote water reuse** and to show that several treatment trains can achieve the requirements to match the supply and demand of wastewater in the zones at risk of water scarcity identified within Stage I. The evaluation system also contains a wide range of content, descriptions, figures and resources and can therefore also be used for capacity building purposes. The assessment should be considered as a pre-feasibility study, where options are proposed and can be compared. This should lead to awareness raising of users and stakeholders addressed by this assessment on the potential of water reuse compared, for example, to the exploitation of new water sources. However, the system should not be seen as a design support system. For further in-depth feasibility studies and design of treatment trains, there are more sophisticated models available (Hamouda, Anderson, & Huck, 2009) and the intervention of experts, engineers and planners is normally mandatory.

The system developed in WP4 is intended to cover a very broad range of scenarios for water reuse and the results is understandable by a wide range of users, also non-experts. However, the reality involved for the real implementation of a water reuse scheme implies additional local specificities and technical information details that cannot be included in a system as holistic as the stage II assessment. The results obtained should therefore always be considered with a pinch of salt, mostly because of resulting uncertainties. The results reliability and uncertainty of results hasn't been tested at the time of writing, but it is a foreseen activity for the 4th year of the Coroado project, where the system will be applied to the 4 study sites and the data quality will be improved. In addition, the tool will be applied to already existing case studies and results will be compared with the real data to assess the results relevance and quality.

1.2.5 Integration and user interface

The stage II assessment developed is being integrated within the COROADO online Decision Support System (DSS)[4]. This document presents all the background information required for the integration within the online DSS. The different calculations are presented in the following chapters and the raw data included in the system are presented in the appendixes. The final DSS will be described in another deliverable from WP6. In parallel, an Excel file named "Poseidon" is

[4] Available at the website: www.coroado.tk to be used with Internet Explorer

under development for individual use, and will be delivered additionally. The documentation of the system is structured in the following way in the different sub-chapters:

- **Chapter 1.3**: different water quality parameters of concern for water reuse, with specific focus on the case study sites in Latin-America, the set of parameters considered in the evaluation system, as well as the water quality classes established in order to facilitate the use of the system by non-experts.
- **Chapter 1.4**: Different unit processes and introduces the data provided in Appendix II Unit Processes Factsheets (Page 54) and Appendix III: Unit Process Data (Page 79).
- **Chapter 1.5**: Details on the concept of treatment trains
- **Chapter 1.6**: Cost estimation component
- **Chapter 1.7**: Evaluation criteria considered
- **Chapter 1.9:** Evaluation, filtering, ranking and selection methodology

1.3 Water quality parameters and water quality classes

1.3.1 Wastewater constituents of concern for water recycling and reuse

In order to decide on the level of treatment required to clean wastewater of a sufficient quality for specific reuse, it is important to identify constituents of concern and their concentration. In untreated wastewater, a range of constituents (
Table **2**) can be found which can negatively affect public health, the environment and infrastructure (e.g., corrosion). According to EPA, 2012, all reuse systems should at least have secondary treatment (following a primary one), which addresses suspended solids, most dissolved organic matter, some nutrients and other inorganics. The specific reuse will determine, whether secondary treatment is sufficient or if more stringent cleaning of the wastewater is necessary. This section provides an overview of the most commonly found wastewater constituents.
Table **2** also provides an overview of measured parameters with a focus on those included in this document.

Table 2 Wastewater constituents, their concerns regarding wastewater reuse and commonly measured parameters for water reclamation water quality, adapted from EPA (2004a, 2012) and (Levine & Asano, 2004)

Constituents of concern	Measured parameters	Acronym / unit
Turbidity is the measure of relative clarity of a liquid. The more total suspended solids in the water, the murkier it seems and the higher the turbidity.	Turbidity	Turb /[NTU]
Total suspended solids. Organic contaminants, heavy metals, etc. are absorbed on particles. Suspended matter can shield microorganisms from disinfectants. Excessive amounts of suspended solids cause plugging in irrigation systems.	Total suspended solids	TSS / [mg/l]
Organic chemicals. Aesthetic and nuisance problems. Organics provide food for microorganisms, adversely affect disinfection processes, make water unsuitable for some industrial or other uses, consume oxygen, and may result in acute or chronic effects if reclaimed water is used.	Biochemical oxygen demand	BOD / [mg/l]
	Chemical oxygen demand	COD / [mg/l]
	Total organic carbon	TOC / [mg/l]
Inorganic chemicals and persistent organic chemicals. Some of these organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of reclaimed water for irrigation or other uses.	Specific compounds (e.g., pesticides, pharmaceutical compounds etc.)	
Nutrients. Nitrogen, phosphorus, and potassium are essential nutrients for plant growth and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesired algae (eutrophication).	Total nitrogen	TN / [mg/l]
	Nitrate	NO_3 / [mg/l]
	Total phosphorus	TP / [mg/l]

	Phosphate	PO_4 / [mg/l]
Pathogens. Infectious microorganisms and viruses (pathogens) are present in untreated wastewater according to the prevalence in population and animals connected to the sewer system. Various disinfection methods exist to reduce pathogen loads.	E. coli	No/100 ml (log)
	Faecal coliform	No/100 ml (log)
	Intestinal nematode eggs	No/100 ml (log)

1.3.2 Chemical compounds

The composition of chemical contaminations in wastewater depends on its origin and co-determines which level of treatment is required to produce reclaimed water for a specific application. Inorganic compounds include nutrients, heavy metals and salts while organic compounds include organic matter, organic detergents etc.

1.3.3 Organic chemicals

Organic pollution originates from fecal matter, kitchen wastes, detergents, oil, industrial wastes etc. Both chemical and biological processes acting on organic chemicals in the wastewater stream require oxygen and the level of organic pollution can be determined through BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand). Also TOC (Total Organic Carbon), and indirectly TSS and turbidity, are commonly used measures of organic pollution in the wastewater stream. BOD refers to the amount of dissolved oxygen (usually mg O_2 per L wastewater) required to degrade organic material by aerobic organisms in a given wastewater at a standard temperature over a standard time (e.g. BOD_5 over five days at 20°C). The COD uses strong oxidizing agents instead of aerobic microorganisms and is thus a measure for the overall content or organic chemical compounds. Also COD is usually measured in mg O_2 per L wastewater. TOC refers to the fraction of TC (Total Carbon) which is bound in organic compounds and includes natural organic matter and synthetic sources such as detergents, fertilizers, herbicides, industrial chemicals etc. All these measures are used as indicators of the overall removal efficiency of sewage treatment plants (Salgot & Huertas, 2006) measured before and after treatment. The effects of high organic chemical loads include coloration and odor problems of the water, possible soil contamination if used for irrigation, depleted oxygen content in the receiving environmental waters (lakes and streams) through decomposition processes by microorganisms and use limitation (many industrial applications require water with low organic contents). Furthermore, since organic contaminations are often associated with suspended solids, high turbidity can reduce the effectiveness of disinfection involving chlorine, UV light or other disinfectants. High BOD in streams and rivers may reduce dissolved oxygen to levels that are inadequate to support aquatic organisms and is thus a limiting factor for environmental reuse (e.g. stream regulation, pond water etc.).

1.3.3.1 Inorganic chemicals and persistent organic pollutants

Inorganic chemicals such as total dissolved solids, nutrients (nitrogen and phosphorus compounds, see next chapter), heavy metals etc. and persistent organic pollutants (POPs) such as pesticides, some by-products of chemical industries etc. can affect the reuse potential secondary effluents from wastewater treatment plants and the need to install further cleaning stages. Inorganic chemicals and POPs are not readily removed by conventional water treatment, since they are often dissolved and in many cases not biologically degraded (Salgot & Huertas, 2006). Many of these substances are harmful to aquatic organisms and are thus problematic for environmental reuse. Some substances are directly harmful to humans and can accumulate in organs.

Total dissolved solids, salts. Various inorganic chemicals are of particular concern for agricultural reuse, especially salts. Irrigation water with a high salinity can degrade soils over time and cause leaf burn. High boron and sodium concentrations of more than 0.4 mg L^{-1} have detrimental effects on some crops such as citrus plants (Salgot & Huertas, 2006). In urban and industrial applications, scaling and corrosion can be concerns. While salinity removal is possible in water treatment, it is quite expensive and energy intensive (EPA, 2012).
Heavy metals. Heavy metals are metals with densities higher than 5 g cm^{-3} (Ravazini et al., 2006) and include for instance Copper, Nickel, Zinc and others. They may accumulate in soils, later into plants and consequently the human food chain. In wastewater from certain industries, especially mining, heavy metals can be an issue. Treatment options to remove heavy metals from wastewater include for instance reverse osmosis (RO) and ion exchange.
POPs, micropollutants. Typical examples of contaminations which have only recently received growing attention in wastewater treatment, drinking water production and water reuse are residues of pharmaceuticals, hormone active substances, pesticides and personal care products. Most of these contaminations are not removed by conventional water treatment and more advanced treatment is required. Advanced methods include Advanced Oxidation Processes (AOPs) and Soil-Aquifer Treatment (SAT).

1.3.3.2 Nutrients

Nutrients are compounds which are essential energy sources for organisms. Nutrients found in wastewater include phosphorus and nitrogen compounds and originate mainly from human and animal excrements, industrial processes and discharge from agricultural areas. Depending on the reuse application, nutrients in the reclaimed water can be beneficial or undesirable. For agricultural reuse, the soil nutrient status can be positively affected by nutrients in the reclaimed water. For environmental or ornamental reuse however (e.g. stream water regulation, pond water etc.) nutrient load should be minimized since otherwise algae growth will be enhanced through nutrient enrichment, leading to oxygen deficits and consequently decay of fish and other animals (a process called eutrophication). The need to remove nutrients during treatment for reuse therefore depends on the intended use of the reclaimed water. Conventional secondary (activated sludge) treatment processes do not significantly remove phosphorus and nitrogen compounds. Since activated sludge treatment is based on microbial degradation of organic substances, nutrients may even be released in more plant available forms (US-EPA, 2004b). Treatment options to remove nutrients from wastewater include for example enhanced biological phosphorus removal (EBPR), P-precipitation, ion exchange and others.

1.3.4 Pathogens

Microorganisms such as bacteria and protozoa are omnipresent in nature and urban environments. In the environment microorganisms are important decomposers of organic matter and therewith provide nutrients for primary production. Most microorganisms are not dangerous to humans and some are even directly beneficial (e.g., intestinal 'flora'). In wastewater engineering, microorganisms help to decompose organic matter and are essential in most secondary water treatment unit trains, such as for instance activated sludge, trickling filters etc. Apart from harmless microorganisms, raw wastewater can contain high concentrations of infectious microorganisms or pathogens, which originate primarily from faeces of infected humans. Pathogens that can be present in urine include those causing schistosomiasis, typhoid fever, leptospirosis and some sexually transmitted infections (however, the latter do not survive for long in wastewater) (EPA, 2012). Waterborne diseases can be transmitted by various pathways, which include the consumption of contaminated water or food via hand-to-mouth contact and the breathing in mist or aerosols from water containing suspended pathogens (e.g. during irrigation).

Since microorganisms and viruses in generally appear in very high concentrations, a logarithmic scale is usually used to report concentrations and removal efficiencies of wastewater treatment processes. For instance, a removal rate of 1log for *E. coli* means that 90 % of the concentration is removed and is calculated according to the following formula:

- For xlog: $100 - 10^{-x}$ = removal efficiency in %
- E.g.: 1log: $100 - 10^{-1}$ = 99.9 %).
- E.g.: 2log: $100 - 10^{-2}$ = 99.99 %).

In general, the presence or absence of microorganisms and viruses in the effluent is analyzed through indicator species. These indicators are used to search for contamination of the water by faeces indicating a high probability of the presence of pathogens (Davide Bixio et al., 2006). The most common types of microorganisms include:

Bacteria. Bacteria are microorganisms of 0.2 to 10 µm length. Many types are present in municipal wastewater. The number and type of bacteria are proportional to their prevalence in the human and animal community from which the wastewater originates (EPA, 2012). Bacteria can be effectively removed from wastewater. Removal efficiencies vary with the level of treatment. A proportion of the bacteria are removed by sedimentation (after adsorption to particulate matter) in primary clarification, secondary clarification and various advanced treatments such as coagulation, flocculation and sedimentation (Appendix). Bacteria can further be removed by filtration including sand filters or membrane processes. In a last step, bacteria can also be inactivated by disinfection. The most commonly used indicator organisms include faecal coliforms and *E. coli*.

Protozoa and helminths. Parasites can be present in different life stages in faeces (adult organisms, spores, cytes, oocysts or eggs) ranging in size from 1 µm to over 60 µm (EPA, 2012). Eggs are most robust against stressors such as heat, freezing and sunlight. In wastewater, helminths can be present as adult, larvae, eggs or ova ranging from 10 µm to more than 100 µm (EPA, 2012). Physical removal by sedimentation or filtration for water reclamation is efficient due to the large size of the organisms. However, both protozoa and helminths can be resistant to disinfection by chlorination or other chemicals. UV light can effectively induce mutations of the DNA of these parasites and inactivate their pathogenicity (EPA, 2012). Commonly used indicators for helminths and nematodes are Nematode eggs. There are no known indicators for protozoa and analytical tools are not yet well developed (Davide Bixio et al., 2006).

Viruses. Viruses occur within size ranges of 0.01 to 0.3 µm (EPA, 2012). Many enteric viruses can cause infections or diseases and are released in faeces. They are generally more adapted to environmental stressors than bacteria. Compared to bacteria and other microorganisms, viruses are less effectively removed by sedimentation and microfiltration processes, due to their small size. Ultrafiltration, nanofiltration and reverse osmosis can achieve significant virus removal. Inactivation of viruses by UV radiation is also efficient, but requires higher doses of UV compared to the inactivation of bacteria and protozoa (EPA, 2012). There is no accepted indicator for viruses yet.

1.3.5 Parameters considered in the stage II assessment

Water quality can be defined by an almost indefinite number of parameters and the topic of water quality is immense and the purpose of many books. Most prominent publications are the WHO guidelines and the EPA guidelines (US-EPA, 2012a; WHO, 2006a). The concentration of any substance or constituent potentially present in wastewater could be a parameter to be analyzed, in addition to all physical, chemical and biological parameters that can be measured. This required a selection of most relevant parameters to be included in the system and this selection has been based on:

- Availability in the Coroado study sites
- Selection of parameters from similar studies

- Data availability of removal performance of the different technologies considered
- Parameters included in the different quality standards and recommendations
- Relevance of several parameters for different intended reuse
- Subjective choice and recommendation by water reuse experts
- Ease to measure and monitor the parameter

After several workshops organized with experts in the field of water reuse, the following 12 water quality parameters have been considered as most relevant for the selection and evaluation of water reuse options in Latin-American contexts, and are integrated in the system:

- Turbidity [NTU]
- Total Suspended Solids TSS [mg/l]
- Biological Oxygen Demand BOD [mg/l]
- Chemical Oxygen Demand COD [mg/l]
- Total N, TN [mg/l]
- Total P, TP [mg/l]
- Fecal Coliform, FC [CFU/100ml]
- Total Coliform, TC [CFU/100ml]
- Total Dissolved Solids, TDS [mg/l]
- Nitrate [mg N/l]
- Total Organic Carbon, TOC [mg/l]
- Virus [PFU/100ml]

1.3.6 Water quality classes

The user of the COROADO online DSS can specify the values of each parameter for the input and intended reuse independently, but if the user is not a specialist, or if he needs some support, descriptive water quality classes have been established to be used in the stage II assessment. Appendix 1 Water Quality Classes Tables (Page 37) provides the quality classes considered with the parameters included in the stage II assessment. It has to be mentioned that some references don't provide limits of constituents for each of the 12 parameters considered. If no value is specified or if not data could be found, the value of "-1" is used in the tables. Those classes will be updated on a continuous basis and can also be edited by the users. There are mainly three types of water quality classes considered:

- Typical wastewater quality that is intended for reuse (e.g. effluent from a WWTP)
- Recommended water quality for and intended use based on guidelines (US-EPA, 2012b; WHO, 2006b)
- Local legislation from the 4 study sites considered for the water quality required for intended reuse or discharge in the environment.

In addition, it is foreseen to establish standard quality classes A-E specific for each of the COROADO study site. Those classes should take into account the national legislation and regulations. However, in some cases, different parameters are not specified in the local regulations and in those cases, it is foreseen to use the recommendations from the WHO and from the AQUAREC project. The work foreseen is to establish pre-defined water quality classes A-E for the 4 COROADO study sites, with parameters that can be edited at a later stage by the user. The quality classes A-E are defined such as:

Class A Water quality is **very low**. Water cannot be reused for any purpose, cannot be discharged and needs treatment.

Class B Water quality is **low**. Water cannot be reused for any purpose but can be discharged according to the national regulations.

Class C Water quality is **medium**. Water could be reused for restricted agricultural (food crops not consumed uncooked) and/or industrial purposes.

Class D Water quality is **good**. Water could be reused for agriculture and other non-potable uses in industry or in the urban network.

Class E Water quality is **excellent**. Water could be reused for potable uses.

1.4 Unit Processes

1.4.1 Factsheets

Work Package 4 developed a technology catalogue (catalogue of unit processes), where the main unit processes are described. Appendix II Unit Processes Factsheets (Page 54) provides this information that is also included in the knowledge base from the COROADO online DSS[5]. Those "factsheets" are intended as a support for capacity building of users who are not familiar with the different technologies and provide a brief description of each technology as well as a figure that helps understand the basics, so that the user is able to understand the suggestions made by the stage II assessment.

1.4.2 Pollutant removal efficiencies

Appendix III: Unit Process Data (Page 79) presents the different removal efficiencies (in %) of each unit process for every parameter considered. For each parameter, the removal performance is provided by three percentages: minimum removal efficiency, average removal, maximum removal efficiency. These data are used in the stage II assessment to calculate the foreseen water quality after treatment. The different percentages used are based on literature (Adewumi, 2011b; Joksimović, 2006b) and with several meetings that have been conducted with experts in the field of water reuse. It has to be understood that a unit process is a simplified concept, as many different types of technologies fit within the same unit process, and that each technology, from each different supplier and applied to different places will all have different performances. However, those estimated removal performances already provide a good estimate for the pre-feasibility stage intended by the stage II assessment developed. The following equation is used for the calculation of the pollutant removal efficiency:

$$C_{eff} = C_{inf} \cdot (1 - R_i), R\epsilon\{R_{min}, R_{avg}, R_{max}\}$$

Where,

C_{eff}: *Effluent concentration [water quality parameter unit]*

C_{inf}: *Influent concentration [water quality parameter unit]*

R_i: *Removal efficiency [%]*

1.5 Treatment Trains

1.5.1 Different stages of treatment

As already mentioned in chapter 1.2.1, unit processes are combined in so-called 'treatment trains'. In order to decide which treatment is required in order to produce water that fits a specific application from a given effluent, water quality of the effluent and water quality needed by the application have to be known. Based on the removal efficiencies of single treatment unit processes, treatment trains can be proposed. The available water quality and the required water quality for a reuse application is the key to propose applicable unit processes and to design appropriate treatment technology.

[5] Available at the website: http://paginas.fe.up.pt/~coroado/wiki.php#googtrans(en|en)

Normally, treatment trains are divided in several stages of treatment with different purposes of removal. In wastewater treatment and reclamation generally the following treatment stages can be distinguished:

- **Primary treatment** refers to unit processes which involve quiescent temporary storage tanks where heavier solids settle to the bottom and lighter wastewater constituents (e.g., oil, grease and solids with a low specific weight) float to the surface. Settled and floating wastewater constituents are removed and the remaining primary effluent either discharged or input into secondary treatment.
- **Secondary treatment** focuses on the removal of biological matter through degradation by microorganisms which are normally present in wastewater. The microorganisms can either grow suspended in the treatment tank ('suspended growth' such as activated sludge processes and membrane bioreactor) or attached to a medium ('attached growth' such as trickling filter, rotating biological contactor and submerged aerated filter). Prior to discharge or tertiary treatment, microorganisms are usually removed from the treated wastewater.
- **Tertiary treatment** can focus on different aspects depending on constituents in the wastewater stream, the intended discharge area in wastewater treatment (e.g. nutrient sensitive areas) and intended reuse application for reuse schemes.
- **Disinfection**. Depending on the discharge or specific reuse application, treated wastewater can be chemically (e.g. by chlorine) or physically (e.g., UV radiation) disinfected.

In general, it is recommended that at least secondary treatment is applied if water is to be re-used for various purposes. (**Error! Reference source not found.**).

1.5.2 Treatment trains included in the stage II assessment

1.5.3 Complexity of the establishment of treatment trains and approach proposed

The stage II assessment considers around 40 unit processes listed in

Table 1 and described in chapter 1.4. The combination of those unit processes can lead to series of maximum 10 unit processes per treatment train. If one considers that every single unit process can be a starting point and that every unit process could be used several times, this leads to about 10^{16} possibilities. Of course most of those possibilities don't make any sense, and many can be directly eliminated. However, this shows the complexity of the process to establish the ideal treatment train given the local situation.

Most existing decision support systems are primarily oriented to experts and are already design programs. (Hamouda et al., 2009) Those are hardly usable and understandable by non-experts or non-specialists in the field of water reuse technologies. The stage II assessment addresses a broad range of users and aims at promoting water reuse. Therefore, it is preferred to use pre-defined treatment trains. The unique approach chosen in the stage II assessment is to propose a list of the most representative treatment trains on the basis of best-practice examples and case studies from literature as well as from expert interviews and local water reuse schemes from Latin-America. At the time of writing, the list is composed of almost 70 treatment trains and will continue evolving (Appendix IV: Treatment trains tables (Page 92)). With this approach, the user of the stage II assessment doesn't need to be an expert in wastewater treatment technologies to proceed to an analysis, as the non-exhaustive list already provides an overview of most common possibilities.

1.5.4 Possibility for experts to create 3 own treatment trains

The system also provides some features for experts, where it is possible to create up to three user-specific treatment trains and evaluate the calculated results. Table 3 proposes unit processes to start treatment trains with, based on the input water quality.

Table 3 Possible starting unit processes (with unit process code) depending on influent water quality (adapted from Joksimovic 2005)

Input water quality	Possible starting unit processes
Raw wastewater	Bar screen, grit chamber, coarse screen, stabilization ponds (*anaerobic, facultative*), activated sludge, EBPR, P-precipitation (*in primary settler*).
Primary effluent	Activated sludge (*high load with sedimentation*), trickling filter, RBC (*pre-requisite: at least fine screen*), stabilization ponds, constructed wetlands, EBPR, P-precipitation, PAC (*in activated sludge systems*).
Secondary effluent	P-precipitation, surface filtration, microfiltration, GAC, PAC, SAT, maturation pond, constructed wetlands (*as polishing step*), flocculation, disinfection.

1.6 Cost estimation

In order to evaluate and select the best option, a typical user first of all wants to know if the technology proposed will meet the technical requirements and achieve the desired water quality required. If the treatment train achieves the water quality, the next piece of information required to support a decision is the cost of treatment and distribution. It is important to insist on the cost of distribution, as those costs are often way more important than the treatment costs. As an example, consider the Figure 3 showing treatment and distribution lifecycle costs of different systems.

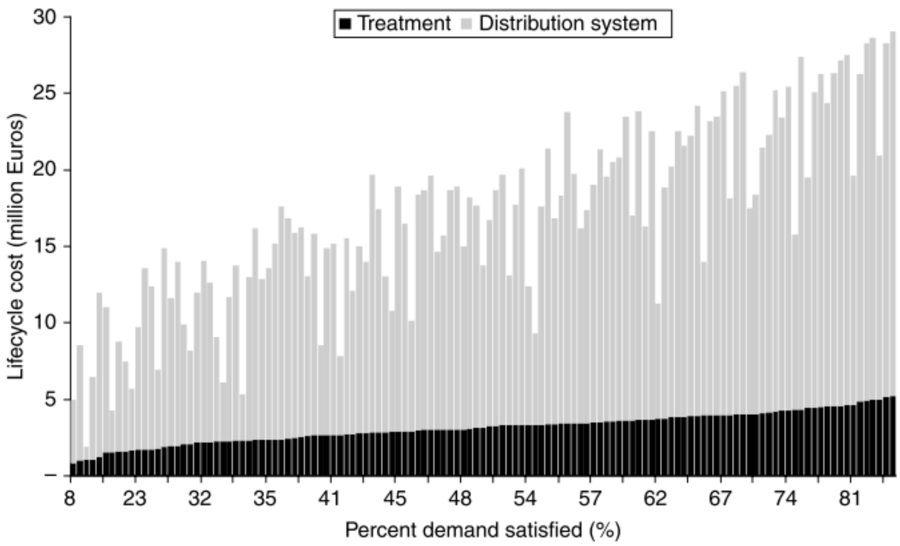

Figure 3: Life cycle cost of different water reuse schemes (Hochstrat, Joksimovic, Wintgens, Melin, & Savic, 2007)

For this purpose, a cost component has been developed within the stage II assessment and results in quantitative figures for the total cost of treatment in local currency per cubic meter of reclaimed water, as well as the distribution costs expressed in the same unit.

The user can select or define several local parameters described in **Table 6**, such as the local currency, electricity costs, land costs, labour costs, water tariff, etc., and the stage II assessment will calculate the results automatically.

The estimation is highly uncertain (a similar study estimates reasonable accuracy to within -30% and +50% of actual costs (Stanford, Debroux, Plumlee, & Reinert, 2013)), as costs are very difficult to estimate for such a wide range of technologies considering local specificities and market prices. However, the stage II assessment already provides first figures and should allow making comparisons between different options at the pre-feasibility stage. It is foreseen to assess the reliability of the quantitative cost results at a later stage.

1.6.1 Simulations of the programme WTRNet conducted as a basis reference for the elaboration of regressions

The first version of the cost component is based on the program WTRNet, from the Aquarec Project[6] (Joksimović, 2006a). Several flows presented in Table 4 with standard pollutant limits defined in Table 5 have been tested with the program. A total of 336 simulations have been conducted (*8 different flows and 42 unit processes*), and for each simulation the following results have been collected: construction costs [EUR], land requirement [ha], energy required [kWh/y], labour requirement [person-hour/month], sludge production [ton/y], concentrate production [m^3/y] as well as total annual operation and maintenance cost [EUR/y].

Table 4: Different flows considered for the regressions of the cost curves.

Average flow [m3/day]	Serviced Population [capita]	Peak flow [m3/h]
10	50	1
20	100	2
200	1,000	20
1,000	5,000	100
2,000	10,000	200
4,000	20,000	400
10,000	50,000	1,000
20,000	100,000	2,000

Table 5: Water quality parameters considered for the regressions of the cost curves

Parameter	Unit	Raw Wastewater	Potable reuse
Turbidity	NTU	225	10
TSS	mg/l	250	10
BOD	mg/l	220	20
COD	mg/l	600	70
TN	mg/l	55	10
TP	mg/l	9	0.2
FC	mg/l	1E6	200
INEggs	No/100ml	800	0.1
Ecoli	No/100ml	0	0

1.6.2 Regressions conducted for the elaboration of cost curves

The data collected from the different simulations has been converted to USD from 2006 with the conversion factor of 1.1825[7] and classified in the following categories: construction costs [1,000

[6] The project Aquarec has been funded by the European commission and the project results are publicly available, such as the manual for water reuse. (Davide Bixio et al., 2006)
[7] As the programme is dated from 2006 and the data source is not clearly described within the WTRNet programme documentation, it has been assumed that 2006 is the reference year. It

USD 2006], land requirement [ha], energy required [kWh/y], labour requirement [person-hour/month], as well as total annual operation and maintenance cost including sludge and concentrate production [1,000 USD2006/y]. Sludge and concentrate production have been included within total operation and maintenance costs, as only few unit processes are concerned and also for simplification purposes. After the conversion and classification step, a total of 336 regressions have been performed as shown in **Figure 4**. Power regressions have been applied, as the cost equations from the WTRNet programme also follow an exponential pattern. This also makes sense from an economic perspective (concept of economy of scale).

In order to simplify the task and not to perform 336 graphics in excel, a linearization has been performed and the Excel function LINEST has been applied, as described below. A typical power regression has the form of:

$y = a \cdot x^b$ ***(power regression from Figure 4)***

If one applies the natural logarithm:

$ln(y) = ln(a) \cdot +b \ \cdot ln(x)$

One obtains a linear equation of the form:

$y = c + d \cdot x$ *(linear regression from Figure 4)*

where:
$c = \ ln(a), d = b, a = exp(c)$

Therefore, the following Microsoft Excel functions have been applied:

a=EXP(INTERCEPT(LN(range of construction costs),LN(range of average flows)))
b=LINEST(LN(range of construction costs),LN(range of average flows),TRUE,TRUE)

Those regressions lead to a database of the regression coefficients for every unit process and every cost component category as a function of the average flow rate and is presented in Appendix V. Each cost factor considered is calculated with an equation in the form of:

$y = \ a \cdot Q^b$

Where:
Q = Average flow [m3/day]
y = any cost component calculated

Only flows with a corresponding cost component value different from 0 have been considered and inconsistencies have been removed from the regressions.

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would be possible to include inflation and Construction Cost Index and Building Cost index but this is not in the scope of the present assessment. The currency exchange rate is taken from the European Commission monthly accounting rate of Euro available at
http://ec.europa.eu/budget/contracts_grants/info_contracts/inforeuro/inforeuro_en.cfm

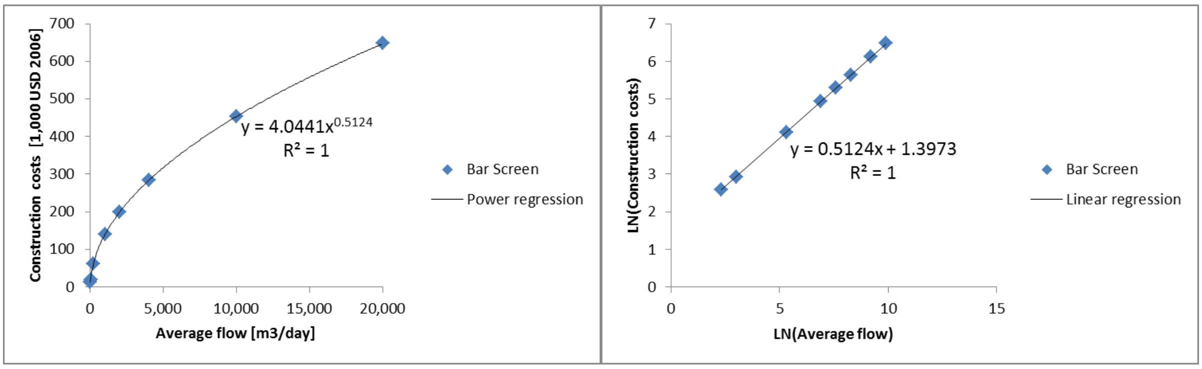

Figure 4: Example of the regressions obtained for the construction costs of the bar screen unit process as a function of the average flow.

1.6.3 Deviations from WTRNet database and additional data

Some unit processes are not included in WTRnet and the following has been added to the database:

- Equalization tank: the total annual costs from a concrete tank have been used and calculated as described in chapter 1.6.6.2. A retention time of 1 day has been applied.
- General process activated sludge and extended aeration: cost data from High Loaded Activated Sludge + Sec. Sedimentation have been used.
- Dual media filter: cost data from filtration over fine porous media have been used
- Denitrification: cost data from P-precipitation have been used and will be updated on a second stage.
- Electrodialysis: data from ion exchange have been used for the time being and electricity requirements of 2.9 kWh/m3 have been applied (Lazarova, 2012)[8]

Furthermore, the regressions system applied allows improving the cost database if necessary. If more data become available it is possible to update the regressions accordingly.

1.6.4 Community profiles for cost analysis

The cost component developed allows adapting the results to the local conditions by adapting several parameters in so-called community profiles. Those parameters are used in the cost calculation in order to obtain locally-specific results. For each community, or study site, the following criteria can be specified:

Table 6: Parameters considered in the community profiles for the calculation of the cost component

Parameter	Unit	Default value	Comment
Currency	[CUR]	USD	The reference community is based on USD from 2006.
Exchange rate to USD 2006	[CUR / USD2006]	1	To define the exchange rate, it is recommended to use the exchange rate from 20069 and to eventually include inflation rate or other

[8] Lazarova, V., Choo, K. and Cornel, P. (eds). 2012. Water-Energy Interactions in Water Reuse. London, IWA Publishing , fig. 23.1, p. 316

9 The following website from the European Commission offer a currency exchange module for different years: http://ec.europa.eu/budget/contracts_grants/info_contracts/inforeuro/inforeuro_en.cfm

			evolution factors since 2006.
Land cost	[CUR/ha]	10,000	Acquisition costs and the unit costs for land has to be merged into this overall land cost factor.
Electricity cost	[CUR/kWh]	0.05	Average electricity cost should be used.
Personal cost	[CUR/ph]	20	Average labour cost should be used covering a mix of different type of personnel (blue and white collar).
Water tariff - households	[CUR/m^3]	2	Selling price of reclaimed water
Water tariff - industry	[CUR/m^3]	2	
Water tariff - agriculture	[CUR/m^3]	2	
Discount rate	%	8%	
Piping	%	8%	
Controls & Instrumentation	%	8%	
Site electrical	%	9%	
Site development	%	8%	
Site works	%	6%	
Engineering	%	12%	
Contingency	%	12%	

1.6.5 Calculation of annualised treatment costs

In order to make results comparable and easy to understand, it has been chosen to calculate every cost in local currency per m^3 [CUR/m^3] of reclaimed water based on annualised lifecycle costs. The procedure applied is to calculate every cost component independently in annual costs and then to sum it up in order to obtain total lifecycle costs for the whole treatment train (TT).

$$TT_{Ann} = \sum_{i=1}^{N} (CAPEX_{Ann} + O\&M_{Ann} + Land_{Ann} + Energy_{Ann} + Labour_{Ann})$$

Where:
TT_{Ann} = *Treatment Train total annual cost [CUR/y]*
N = number of unit processes i in the treatment train (TT) considered [-]
$CAPEX_{Ann}$ = *Annualised capital cost of unit process i [CUR/y]*
$O\&M_{Ann}$ = *Annualised operation and maintenance cost of unit process i [CUR/y]*
$Land_{Ann}$ = *Annualised land cost of unit process i [CUR/y]*
$Energy_{Ann}$ = *Annualised energy cost of unit process i [CUR/y]*
$Labour_{Ann}$ = *Annualised labour cost of unit process i [CUR/y]*

The different cost components are calculated for each unit process independently. Then, dividing this number by the annual volume of reclaimed water, one obtains the annualised treatment costs in [CUR/m^3] of reclaimed water, as of:

$$Treatment\ cost_{Ann} = \frac{TT_{Ann}}{V_{Ann}}$$

Where:
$Treatment\ cost_{Ann}$ = *Annualised unit cost of treatment per m^3 of reclaimed water [CUR/y/m^3]*
TT_{Ann} = *Treatment Train total annual cost [CUR/y]*
V_{Ann} = *volume of reclaimed water produced annually [m^3]*

1.6.5.1 Annualised capital costs calculation

In order to calculate the total capital costs for every unit process, the standard capital cost algorithm presented in **Table 7** has been used. All equipment costs are first calculated with the regressions described before and depending on the flow. It has to be noted that the flow takes into account the recovery percentage of each unit process. For example, if a sequence of two unit processes is considered with the first unit process having a recovery of 50%: if the inflow in the first unit process is 1,000 [m^3/day], the inflow in the second unit process considered for cost calculation will be 500 [m^3/day].

Table 7: Standard capital cost algorithm applied (adapted from (Joksimović, 2006a; US-EPA, 2000a))

Factor	**Used in the system**	**Default value**
Equipment cost (EC)	Technology-specific cost rom the regressions defined in chapter 1.6.2.	EC
Installation	Site electrical	9% of EC
	Site development	8% of EC
	Site works	6% of EC
Piping		8% of EC
Instrumentation and controls		8% of EC
Total construction cost (CC)	Equipment + installation + piping + instrumentation and controls	39% of EC
Engineering	12% of total construction cost	12% of CC
Contingency	15% of total construction cost	15% of CC
Total indirect cost	Engineering + contingency	27% of CC
Total capital cost (CAPEX)	Total construction cost + Total indirect cost	CAPEX = (1.39*EC)*1.27

Equipment costs and therefore total capital cost for every unit process can be calculated independently for theoretically every possible flow between 10 and 20,000 [m^3/day][10]. The resulting total capital costs have to be annualised based on the useful life of every unit process considered. For the annualisation, the following capital recovery factor (CRF) is used:

$$CRF = \frac{r \cdot (1+r)^n}{(1+r)^n - 1} = \frac{r}{1-(1+r)^{-n}}$$

Where:
CRF = Capital Recovery Factor [y^{-1}]
r = discount rate[11] [-]

[10] This is the range of the regressions carried out and described in chapter 1.6.2. The application range might be wider but has not been tested neither validated. It is expected that results are mostly subject to error for very low and very high flows mostly because of the economy of scale effect.
[11] Discount rate takes into account the interest rate and the inflation. Default value of 8% is used.

n = useful life of the unit process [y]

The discount rate is defined by the Fisher equation:

$$r = \frac{1+i}{1+p} - 1 \approx i - p$$

Where:
r = discount rate (default value of 8%) [-]
i = interest rate [-]
p = actual inflation rate [-]

The total capital cost multiplied by CRF results in annualised capital costs.

1.6.5.2 Operation and Maintenance costs (O&M, OPEX)

The operation and maintenance costs used in the cost component are from the different regressions carried out and costs for sludge and concentrate disposal have been integrated to those costs. Therefore the O&M costs consist in: (US-EPA, 2000a)

- Maintenance (usually 4% of total capital costs)
- Taxes and insurance (usually 2% of total capital cost)
- Chemicals (*Lime/calcium hydroxide, polymer, sodium hydroxide, sodium hypochlorite, sulfuric acid, cationic polymer, ferrous sulfate, hydrated lime, sodium sulfide*)
- Residual management (technology-specific costs)
- Sludge disposal
- Concentrate disposal

The land costs, energy costs and labour costs are calculated separately and are not included in operation and maintenance costs. This allows simplify the calculations in order to vary those costs to local situations and different electricity, land and labour costs.

1.6.5.3 Land, energy and labour costs

The following parameters are calculated for every unit process:

- Land requirement [ha]
- Electricity requirement [kWh/year]
- Labour requirements [person-hour/month]

In order to obtain land, energy and labour costs, it is only necessary to multiply those parameters with the corresponding ones from **Table 6**. One obtains electricity and labour costs already per year, and for the land costs, an annualisation is also necessary. The calculation applied is the same as for the annualisation of the total capital costs described in chapter 1.6.5.1. It has been chosen to an annualisation period of 30 years for the land and to apply corresponding land unit costs. This timeframe has been chosen, as most unit processes considered have a useful life of 30 years. In practice, this means that if the total cost of land is 100,000 [USD] with a discount rate of 8% and an annualisation period of 30 years, the annual costs would be:

*100,000 [USD] * CRF (0.089) [y^{-1}] = 8,883 [USD/y].*

Where:
CRF = Capital Recovery Factor [y^{-1}]

Using a fixed period of 30 years is a simplification and the user should be aware that the residual value of the land after 30 years is not considered in the calculation. Furthermore, if the capital used for buying the land is public or private, it might lead to differences and another factor is that the period might be longer. If the period is rather 100 years, the resulting annual land costs would be 8,000 [USD/y], a difference of around 11%. The influence of this difference on the final cost of treatment is insignificant compared to the expected uncertainty of the final cost of treatment calculated with this model. However, the user should be aware of this fact and for example, the land is already owned by the user, one should enter land costs = 0 [CUR/ha].

1.6.6 Distribution component

1.6.6.1 Pumps

The calculation for the distribution component have been taken over from (Joksimović, 2006a) that is based on (Heaney et al. 1999)[12] and (Oron 1996)[13]. The following two main equations are used for the pumping costs calculation:

Pumping capital costs

$$CAPEX = (21{,}715 * H * Q^{0.52})$$

Where:
CAPEX = pumping station capital cost [CUR]
H = required pumping head [m
Q = design flow rate [l/s]
Note: In addition, 5% of the capital cost is used for annual maintenance. For the annualisation of the capital costs, a useful life of 15 years is used and the same procedure with the Capital Recovery Factor is applied.

Pumping energy required

$$CE = \theta_{hp} \cdot C_e \cdot \frac{V_{ann} \cdot H}{2.7 \cdot \eta}$$

Where:
CE = Annual cost of energy required for pumping [CUR]
θ_{hp} = conversion factor to kWh (θ_{hp}=0.746)
C_e = unit cost of energy [CUR/kWh]
V_{ann} = volume of water pumped annually [m^3]
H = pressure head required at the pump [m]
η = pump efficiency [%], (default value of 65%)

1.6.6.2 Storage facilities

Four different types of storage are considered: reservoir, concrete tank, covered concrete tank and earthen basin. The following equation is applied for the costs calculation:

$$UCS = C_1 \cdot V^{C_2}$$

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12 Heaney, J. P., Sample, D., and Wright, L. (1999). "Cost Analysis and Financing of Urban Water Infrastructure." Innovative Urban Wet-Weather Flow Management Systems, J. P. Heaney, R. Pitt, and R. Field, eds., United States Environmental Protection Agency, Office of Water, Washington, DC, 30.
13 Oron, G. (1996). "Management Modelling of Integrative Wastewater Treatment and Reuse Systems." Water Science and Technology, 33(10-11), 95-105.

Where:
UCS = Unit cost of storage facility [CUR]
C_i = Cost coefficients from **Table 8**
V = Storage volume [m^3]
Note: In addition, 0.5% of the capital cost is used for annual maintenance. For the annualisation of the capital costs, a useful life of 30 years is used and the same procedure with the Capital Recovery Factor is applied.

Table 8: Storage facilities cost coefficients

Storage type	C_1	C_2
Reservoir	15,093	-0.60
Concrete tank	1,238	-0.19
Covered concrete tank	5,575	-0.39
Earthen basin	128	-0.24

1.6.6.3 Pipe

The cost curves for the pipe cost also come from (Joksimović, 2006a) that derived the equations from data on the costs of installed pipes provided by UK water companies (OFWAT 2000) and reported in (USEPA 2002a)[14]. The model proposes pipe costs coefficient for 3 different types of land use: grassland, rural/suburban and urban. The following equation is applied:

$$CP = C_1 \cdot e^{C_2 \cdot D}$$

Where:
CP = Pipe unit cost [CUR/m]
C_i = Cost coefficients from **Table 9**
D = Pipe diameter [m]
Note: In addition, 3% of the capital cost is used for annual maintenance. For the annualisation of the capital costs, a useful life of 50 years is used and the same procedure with the Capital Recovery Factor is applied.

Table 9: Pipe unit cost coefficients

Land use	C_1	C_2
Grassland	47.47	3.51
Rural/suburban	96.19	3.07
Urban	129.42	2.72

1.6.6.4 Required parameters

Based on the cost curves equations described in previous chapters, the following parameters are required in order to calculate all incurring distribution costs:

Table 10: Input parameters required for the calculation of the distribution costs

Parameter	Unit	Note

[14] USEPA. (2002a). "Decision-Support Tools for Predicting the Performance of Water Distribution and Wastewater Collection Systems." EPA 600/R-02/029, United States Environmental Protection Agency, Office of Research and Development, Washington, DC.

Length of pipe	*[m]*	Defined by the user
Pipe Diameter (D)	*[mm]*	Calculated by the simple design model presented in chapter 1.6.6.7.
Elevation (+uphill, -downhill)	*[m]*	Defined by the user. Please note that a negative elevation will not bring revenue to the model but will only annihilate the head due to friction and result in costs of zero. If the user plans to recover the energy, it has to be calculated independently.
Volume of water pumped annually (V_{ann})	*[m³]*	Calculated by the system based on the flow (*if the distribution is before the treatment the inflow is used, if it is after the treatment, the flow calculated with the treatment train recovery is used*)
Pressure head required at the pump (H)	*[m]*	Calculated with the Hazen-Williams equation as described in chapter 1.6.6.6.
Design flow rate (Q)	*[l/s]*	Calculated by the system based on the flow (*if the distribution is before the treatment the inflow is used, if it is after the treatment, the flow calculated with the treatment train recovery is used*)
Storage volume (V)	*[m³]*	Defined by the user

The biggest challenge in estimating costs for distribution is to estimate the appropriate design, namely the diameter of the pipes that will influence the velocity, pumping costs and piping costs. Once the design is fixed, the head loss can be calculated and added to the elevation in order to calculate the pressure head required for pumping.

1.6.6.5 Calculation of the frictional head loss

In order to calculate the pressure head required for pumping, the Hazen-Williams equation is used. Note that the Hazen-Williams formula is empirical and lacks a theoretical basis. Be aware that the roughness coefficient are based on "normal" condition with approximately 1 m/s. (http://www.engineeringtoolbox.com/)

$$\boldsymbol{h_f = L \cdot \left(\frac{10.67 \cdot Q^{1.85}}{C^{1.85} \cdot d^{4.87}}\right)}$$

Where:
h_f = Head loss over the length of pipe [m]
L = length of pipe [m]
Q = volumetric flow rate [m³/s]
C = Pipe roughness coefficient (default value of 140)
d =inside pipe diameter [m]
Note: in the programme the equation using imperial units is used and converted.

1.6.6.6 Calculation of the pressure head required for pumping

$$\boldsymbol{H = h_f + Elevation}$$

Where:
H = pressure head required at the pump [m]
h_f = Head loss over the length of pipe [m]
Elevation = Altitude difference between the beginning and end of the pipe, positive or negative. [m]

1.6.6.7 Simple design model for the definition of the pipe diameter

One can see that the only unknown parameter is the inside pipe diameter. In order to determine this parameter, the assumption has been made that the velocity of the fluid should be 1 [m/s]. If the water velocity is fixed, one can obtain the internal diameter using the following equation:

$$d = 2000 \cdot \sqrt{\frac{Q}{v \cdot \pi}}$$

Where:
d =Inside pipe diameter [m]
Q = Volumetric flow rate [m³/s]
v = Flow velocity [m/s] (default value of 1)

1.6.6.8 Calculation of the total annual distribution lifecycle costs

In order to make results comparable and easy to understand, the distribution costs has also been calculated in cost per m^3 of reclaimed water based on annualised lifecycle costs. The following equation is applied:

$$Dist_{Ann} = Pump1_{Ann} + Pipe1_{Ann} + Storage_{Ann} + Pump2_{Ann} + Pipe2_{Ann}$$

Where:
$Dist_{Ann}$ *= Total annual distribution cost [CUR/y]*
$Pump1_{Ann}$ *= Annualised pumping costs [CUR/y]*
$Pipe1_{Ann}$ *= Annualised piping costs [CUR/y]*
$Storage_{Ann}$ *= Annualised storage costs [CUR/y]*
$Pump2_{Ann}$ *= Annualised pumping costs [CUR/y]*
$Pipe2_{Ann}$ *= Annualised piping costs [CUR/y]*

Then, in order to obtain the annualised distribution costs in [CUR] per m^3 of reclaimed water, the following equation is applied:

$$Distribution\ cost_{Ann} = \frac{Dist_{Ann}}{V_{Ann}}$$

Where:
$Distribution\ cost_{Ann}$ *= Annualised unit cost of distribution per* m^3 *of reclaimed water [CUR/y/*m^3*]*
$Dist_{Ann}$ *= Total annual distribution cost [CUR/y]*
V_{Ann} *= volume of reclaimed water produced annually [*m^3*]*

1.6.7 Conclusions of the cost component from the stage II assessment

The cost component described in the previous chapters offers an important piece of information for the evaluation, comparison and selection of the different treatment trains, as costs is often one of the key aspects considered. Using annualised costs per cubic meter makes it easy to compare and understand the influence of different factors and if required additional costs are also calculated (e.g. total CAPEX). The models on which this assessment is based provide usually good results and allows for a comparison of different options. The reliability of this cost component has not been tested at the time of writing but it is expected that the results comply with the requirements of the WP4 stage II assessment at a pre-feasibility stage. If different treatment trains are more seriously considered, a deeper cost assessment should be conducted.

1.7 Evaluation Criteria

In addition to the pollutants removal performance and the quantitative cost component, the stage II assessment also considers additional evaluation criteria, requirements and impacts described in this chapter. Same as for the other components, a database assigns the different values for each unit process independently and the treatment train evaluation criteria are calculated as described below. Some criteria are fixed per unit process based on work by Urkiaga et al. (2006b), some are derived from quantitative results (e.g. cost of treatment) and therefore dependent on the condition specified by the user (e.g. volume of water treated, cost of electricity, etc.). This chapter is divided into:

- Technical evaluation criteria of the treatment trains (chapter 1.7.1)
- Requirements and impacts (chapter 1.7.2)
- Normalised costs component (chapter 1.7.3)

The possible values for the indicators are:

0. nil
1. low
2. medium
3. high

1.7.1 Technical evaluation criteria

In complement to the pollutant removal, technical evaluation criteria refer to desired effects by the installation of a certain process. Important factors include the reliability of the process, the ease to upgrade if the wastewater stream increases (e.g. population growth), the adaptability to varying wastewater flows (e.g. seasonal differences), the adaptability to varying influent wastewater quality, the ease of operation and management (e.g. requirements for specially trained personnel, dosing of certain substances), the ease of construction (overall estimate of the ease to install a unit process based on additional installations required, human resources and specialists needed etc.) and ease of demonstration. Those 7 indicators are qualitative and a value is provided for each unit process in a database presented in Appendix III: Unit Process Data (Page 79).

Table 11 Technical evaluation criteria

Evaluation criteria (EC) (0 = nil, 1 = low, 2 = medium, and 3 = high)						
Reliability (Qualitative)	**Ease to Upgrade** (Qualitative)	**Adaptability to varying flow** (Qualitative)	**Adaptability to varying quality** (Qualitative)	**Ease of O & M** (Qualitative)	**Ease of Construction** (Qualitative)	**Ease of Demonstratio n** (Qualitative)

The calculation of an average evaluation criteria score for different treatment trains is made using the following equation:

$$AE_i^{TT} = \frac{\sum_j^N EC_{ij}^{UP}}{N}$$

Where:
AE_i^{TT} *= Treatment train average evaluation criteria score for criteria i [-]*
EC_{ij}^{UP} *= Evaluation criteria i value for unit process j [-]*
N = Number of unit processes in the treatment train [-]

1.7.2 Technical and environmental requirements and impacts

Significant operational requirements and environmental impacts are evaluated for each unit process. This includes energy demand (which is often the most important operational cost), chemical demand (e.g. chloride), land requirement (area needed to install a certain unit process), impact on groundwater, odor generation and quantity of sludge production (depending on available area and transport infrastructure, generated sludge can lead to significant cost for transport and disposal).

Table 12 Requirements and impacts

Requirements and impacts (0 = nil, 1 = low, 2 = medium, and 3 = high)						
Power demand (Semi-quantitative)	**Chemical demand** (Qualitative)	**Odour generation** (Qualitative)	**Impact on groundwater** (Qualitative)	**Land requirement** (Semi-quantitative)	**Cost of treatment** (Semi-quantitative)	**Quantity of sludge production** (Semi-quantitative)

For the requirement and impact based on qualitative data, every unit process has an assigned value provided in Appendix III: Unit Process Data (Page 79). For the semi-quantitative ones, the value is based on regressions presented in Appendix V: Cost estimation tables (Page 104), based on the flow. Each value is calculated individually and depends on values entered by the user. The treatment train aggregated score is calculated with the following process (and described in the equation below):

- Summing up the scores of every unit processes involved in the treatment train
- *Normalization*: dividing the sum by the highest criteria value from all treatment trains considered
- Multiply by 3 in order to obtain values in the range [0;3]

$$RI_i^{TT} = 3 * \left(\frac{\sum_j^N RI_{ij}^{UP}}{MAX \underbrace{\left\{\sum_j^N RI_{ij}^{UP}\right\}}_{i}} \right)$$

Where:
RI_i^{TT} *= Treatment train average requirements and impacts criteria score for criteria i [-]*
RI_{ij}^{UP} *= Requirement and Impact criteria i value for unit process j [-]*
N = Number of unit processes in the treatment train [-]

1.7.3 Costs

Costs (0 = nil, 1 = low, 2 = medium, and 3 = high)						
Annualised Capital Costs (Semi-quantitative)	**Land Cost** (Semi-quantitative)	**Energy cost** (Semi-quantitative)	**Labour** (Semi-quantitative)	**O&M Others** (Semi-quantitative)	**Total Annualised costs** (Semi-quantitative)	

The calculation is the same as the one used for the requirements and impacts:

$$C_i^{TT} = 3 * \left(\frac{\sum_j^N C_{ij}^{UP}}{MAX \overbrace{\left\{\sum_j^N C_{ij}^{UP}\right\}}^{i}} \right)$$

Where:
C_i^{TT} *= Treatment train average requirements and impacts criteria score for criteria i [-]*
C_{ij}^{UP} *= Requirement and Impact criteria i value for unit process j [-]*
N = Number of unit processes in the treatment train [-]

1.8 Ranking, filtering, evaluation and selection

Water reuse systems and applicable unit processes cannot be selected based only on removal efficiencies of wastewater constituents and costs. In order to choose reuse systems which are adapted to local environmental, economic and social conditions, different systems and their unit processes should be compared based on defined selection criteria, such as energy requirements, land requirements, ease of construction or any of the evaluation criteria included in the system. At a preliminary stage, different options need to be discussed between different stakeholders and often a community consultation process is either required or recommended. It is therefore useful to have a good knowledge not only regarding removal efficiencies, but also of environmental, economic and social aspects.

1.8.1 Calculation of an overall treatment train evaluation score

For the calculation of a treatment train overall evaluation score, the weighs that can be user defined are used and the following process is applied:

- The user specifies the importance of the different evaluation criteria and requirements & impacts in the following range (0-4):

0. *Not important (not considered)*
1. *Not very important*
2. *Regular*
3. *Important*
4. *Very important*

- The following criteria are normalized to a value between 0 and 1. (The criterias defined before between 0-3 are just divided by 3 and the quantitative criteria divided by the highest value of the list of treatment trains considered.
- For the criteria evaluated as negative (requirement and impacts, costs), the following formula is applied: 1-NC_i^{TT} in order to have everything in positive for the overall evaluation score.

The calculation of the treatment train overall evaluation score is made using the following equation:

$$OE^{TT} = 3 \cdot \left(\frac{\sum_{i=1}^{M} W_i \cdot NC_i^{TT}}{\sum W_i} \right)$$

Where:
OE^{TT} = treatment train overall evaluation score *[-] (range 0-3)*

W_i = Weight of criteria i [-] (range 0-4, user-defined)
NC_i^{TT} = Normalised criteria i score [-] (range 0-1)
M = Number of evaluation criteria [-]

1.9 Overview of results for the filtering, ranking, selection and evaluation

The stage II assessment described in this chapter results in the following results for every treatment trains:

- Technical pollutant removal efficiencies
- Quantitative cost (treatment and distribution)
- Independent evaluation score
- Independent scores for requirement and impacts
- Treatment train overall evaluation score (with weights that are assigned by the user)

On one side, the WP7 will use these results to propose a multi-criteria analysis to be integrated within WP6 online tool, where several criterions can be compared and analyzed. On the other side, the stage II assessment proposes a simple ranking methodology described in chapter 1.2.3.

1.9.1 Calculations and Results

The data and knowledge collected and presented along chapter 1**Error! Reference source not ound.** provides the background for the elaboration and integration of an evaluation system within the Coroado DSS tools. At the time of writing this deliverable, the exact methodology that will be applied by WP6 to develop the tool and from WP7 to compare and assess different strategy is still not completely defined. Nevertheless, it is foreseen to proceed as follows:

- Using the data from Stage I, start to analyze a specific scenario/strategy in one case study in a zone identified at risk of water stress. Specific local data, such as electricity costs and other parameters necessary.
- Assign a water quality class to the influent and specify the available water quantity for treatment
- Specify the intended reuse of the reclaimed water and the required quantity
- Specify if distribution/storage is required, and if so what type of distribution and for which distance. The distance can be derived from the Stage I assessment.
- Calculate the removal performances of each treatment trains included in the system
- Based on the results, only keep the treatment trains that achieve the required water quality
- Rank the treatment trains left based on the total cost of treatment and distribution
- Consider the other evaluation criteria

And finally propose the best treatment train(s) to the user.

1.10 Application and results

It is foreseen to apply the system in the 4th year of the Coroado project and results are not available yet. Nevertheless, several generic examples will be added after the workshop in Chile.

2 References

Adewumi, J. R. (2011a). A decision support system for assessing the feasibility of implementing wastewater reuse in South Africa.
Adewumi, J. R. (2011b). A decision support system for assessing the feasibility of implementing wastewater reuse in South Africa.
Bixio, D., Weemaes, M., Thoeye, C., Ravazini, A., Miska, V., De Koning, J., … Melin, T. (2006). Water reuse system management manual. Aquarec. (D. Bixio & T. Wintgens, Eds.) (p. 676). Luxembourg: Office for Official Publications of the European Communities.
Bryan, D., Chambers, B., & Cooper, P. (1995). Wastewater and sludge treatment processes (p. 190). Wiltshire, UK: WRc [Water Research Centre].
EPA. (1999). Alternative disinfectants and oxidants guidance manual (p. 30). Washington DC, USA: EPA [United States Environmental Protection Agency].
EPA. (2000). Wastewater technology fact sheet. Granular activated carbon adsorption and regeneration. Washington DC, USA: EPA [United States Environmental Protection Agency].
EPA. (2012). 2012 Guidelines for Water Reuse (p. 643). Washington DC, USA: EPA [United States Environmental Protection Agency].
Hammer, M. J., & Hammer, M. J. J. (2012). Water and wastewater technology (7th ed.). Boston: Pearson/Prentice Hall.
Hamouda, M. A., Anderson, W. B., & Huck, P. M. (2009). Decision support systems in water and wastewater treatment process selection and design: a review. Water Science & Technology. Retrieved from http://www.iwaponline.com/wst/06007/wst060071757.htm
Hilal, N., Darwish, N. A., Mohammad, A. W., & Arabi, M. A. (2004). A comprehensive review of nanofiltration membranes : Treatment , pretreatment , modelling , and atomic force microscopy, 170, 281–308. doi:10.1016/j.desal.2004.01.007
Hochstrat, R., Joksimovic, D., Wintgens, T., Melin, T., & Savic, D. (2007). Economic considerations and decision support tool for wastewater reuse scheme planning, 175–182. doi:10.2166/wst.2007.570
Hydrotec. (2013). Reverse osmosis.
IEES. (2013). Polishing wastewater in a wetland at Everstekoog, Netherlands.
Infobarscreens. (2013). Infobarscreens.

Adewumi, J. R. (2011a). *A decision support system for assessing the feasibility of implementing wastewater reuse in South Africa*.

Adewumi, J. R. (2011b). *A decision support system for assessing the feasibility of implementing wastewater reuse in South Africa*.

Bixio, D., Thoeye, C., De Koning, J., Joksimovic, D., Savic, D., Wintgens, T., & Melin, T. (2006). Wastewater reuse in Europe. *Desalination*, *187*(1-3), 89–101. doi:10.1016/j.desal.2005.04.070

Bixio, D., Weemaes, M., Thoeye, C., Ravazini, A., Miska, V., De Koning, J., … Melin, T. (2006). *Water reuse system management manual. Aquarec*. (D. Bixio & T. Wintgens, Eds.) (p. 676). Luxembourg: Office for Official Publications of the European Communities.

Bryan, D., Chambers, B., & Cooper, P. (1995). *Wastewater and sludge treatment processes* (p. 190). Wiltshire, UK: WRc [Water Research Centre].

EPA. (1999). *Alternative disinfectants and oxidants guidance manual* (p. 30). Washington DC, USA: EPA [United States Environmental Protection Agency].

EPA. (2000). Wastewater technology fact sheet. Granular activated carbon adsorption and regeneration. Washington DC, USA: EPA [United States Environmental Protection Agency].

EPA. (2012). *2012 Guidelines for Water Reuse* (p. 643). Washington DC, USA: EPA [United States Environmental Protection Agency].

Hammer, M. J., & Hammer, M. J. J. (2012). *Water and wastewater technology* (7th ed.). Boston: Pearson/Prentice Hall.

Hamouda, M. A., Anderson, W. B., & Huck, P. M. (2009). Decision support systems in water and wastewater treatment process selection and design: a review. *Water Science & Technology*. Retrieved from http://www.iwaponline.com/wst/06007/wst060071757.htm

Hilal, N., Darwish, N. A., Mohammad, A. W., & Arabi, M. A. (2004). A comprehensive review of nanofiltration membranes : Treatment , pretreatment , modelling , and atomic force microscopy, *170*, 281–308. doi:10.1016/j.desal.2004.01.007

Hochstrat, R., Joksimovic, D., Wintgens, T., Melin, T., & Savic, D. (2007). Economic considerations and decision support tool for wastewater reuse scheme planning, 175–182. doi:10.2166/wst.2007.570

Hydrotec. (2013). *Reverse osmosis*.

IEES. (2013). *Polishing wastewater in a wetland at Everstekoog, Netherlands*.

Infobarscreens. (2013). *Infobarscreens*.

Joksimovic, D. (Ed.). (2005). *Design support software for water reuse (Aquarec)* (p. 115). Luxembourg: Office for Official Publications of the European Communities.

Joksimović, D. (2006a). *Decision Support System for Planning of Integrated Water Reuse Projects*. University of Exeter.

Joksimović, D. (2006b). *Decision Support System for Planning of Integrated Water Reuse Projects*. University of Exeter.

Landcom. (2006). Wastewater reuse in the Urban Environment: selection of technologies, (February).

Levine, A. D., & Asano, T. (2004). Recovering sustainable water from wastewater. *Environmental Science & Technology*, *45*(203A), 201–208.

Matilainen, A., & Sillanpää, M. (2010). Removal of natural organic matter from drinking water by advanced oxidation processes. *Chemosphere*, *80*(4), 351–65. doi:10.1016/j.chemosphere.2010.04.067

Miotli, K., Barry, K., Dillon, P., & Breton, M. (2010). *Alice Springs SAT Project Hydrological and Water Quality Monitoring Report*. Adelaide, Australia.

Neumann, S., & Fatula, P. (2009). Principles of Ion Exchange in Wastewater Treatment, (March).

Ravazini, A., Miska, V., Jansen, H., De Koning, J., Bixio, D., Thoeye, C., … Aharoni, A. (2006). *Water treatment options in reuse systems. Aquarec*. (J. De Koning, V. Miska, & A. Ravazini, Eds.). Luxembourg: European Commission.

Salgot, M., & Huertas, E. (Eds.). (2006). *Guideline for quality standards for water reuse in Europe (Aquarec)* (p. 126). Luxembourg: Office for Official Publications of the European Communities.

Sandec, & EAWAG. (2013). *Stabilization ponds*.

Stanford, B., Debroux, J.-F., Plumlee, M., & Reinert, A. (2013). Costs of Advanced Treatment in Water Reclamation. In *Water Environment Federation Conference 2013* (pp. 6388–6395).

Urkiaga, A., Fuentes, L. de las, Bis, B., Hernández, F., Koksis, T., Balasz, B., … Melin, T. (2006a). *Handbook on feasibility studies for water reuse systems* (p. 159).

Urkiaga, A., Fuentes, L. de las, Bis, B., Hernández, F., Koksis, T., Balasz, B., … Melin, T. (2006b). *Handbook on feasibility studies for water reuse systems* (p. 159).

US-EPA. (1994). Wastewater Technology Fact Sheet - Screening and Grit Removal.

US-EPA. (1996). Wastewater treatment technologies. *Category, Development Document for the CWT Point Source*.

US-EPA. (1999a). Wastewater Technology Fact Sheet - Ozone Disinfection.

US-EPA. (1999b). Wastewater Technology Fact Sheet - Ultraviolet Disinfection.

US-EPA. (2000a). *Development Document for the CWT Point Source Category - Chapter 11 Cost of treatment technologies*.

US-EPA. (2000b). Wastewater Technology Fact Sheet - Chemical Precipitation.

US-EPA. (2000c). Wastewater Technology Fact Sheet - Trickling Filters.

US-EPA. (2000d). Wastewater Technology Fact Sheet - Wetlands : Subsurface Flow.

US-EPA. (2002). Wastewater Technology Fact Sheet - Ballasted Flocculation.

US-EPA. (2004a). *Guidelines for Water Reuse 2004*.

US-EPA. (2004b). Primer for Municipal Wastewater Treatment Systems, (September).

US-EPA. (2012a). *Guidelines for Water Reuse 2012*.

US-EPA. (2012b). *Guidelines for Water Reuse 2012*.

USFilter. (n.d.). Applying the rotating biological contactor process. Waukesha, USA: USFilter.

Wateen Solutions. (2013). *Carbon filter*.

WHO. (2006a). Guidelines for the safe use of wastewater, excreta and greywater - Volume 2 Wastewater use in agriculture, *11*.

WHO. (2006b). Guidelines for the safe use of wastewater, excreta and greywater - Volume 2 Wastewater use in agriculture, *11*.

Wintgens, T., & Hochstrat, R. (2006). *Integrated Concepts for Reuse of Upgraded Wastewater*. (T. Wintgens & R. Hochstrat, Eds.) (pp. 1–184). Aquarec.

Wintgens, T., Hochstrat, R., Hidalgo, E. H., Salgot, M., Jeffrey, P., Hernández, F., … Balasz, B. (2006). *Report on integrated water reuse concepts (Aquarec)*. (T. Wintgens & R. Hochstrat, Eds.) (p. 184). Luxembourg: Office for Official Publications of the European Communities.

List of Appendixes

Appendix 1 Water Quality Classes Tables

A1.1 Typical wastewater quality (input) that is intended for reuse

(e.g. municipal wastewater quality, industrial wastewater qualities and other wastewater qualities.

The table below indicates a list of typical wastewater qualities for several types of wastewater to be reused. The user can either manually define the quality of the "input flow" or choose from the list below.
The value "-1" means not data available or not applicable/not relevant.

Municipal Wastewater													
Wastewater qualities of potential input	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**Reference/ *Comments***
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
Typical untreated domestic wastewater	100	210	190	430	40	7	10^4-10^5	10^7-10^8	720	0	140	10^1-10^4	Asano et al., 2006 p. 107 *Typical composition of untreated domestic wastewater. Note: there is no typical wastewater, values should only be used as guide!* *Data presented are for medium-strengths wastewater based on average flow of 460 L/cap*day and include constituents added by commercial institutional, and industrial sources.* Value for Turbidity: Asano et al., 2006, p.109 Viruses: Asano et al., 2006, p.110
Untreated domestic wastewater *(ranges)*	-1	120-400	110-350	250-800	20-70	4-12	10^3-10^7	10^6-10^9	270-860	0-trace	80-260	-1	Asano et al., 2006 p. 107
Primary effluent	88	131	149	-1	-1	5.1	-1	-1	-1	0.1	72	-1	Asano et al., 2006 p. 109 *Constituents remaining after primary treatment. Primary treatment consisted of a rotary drum screen , followed by disk screens*

Secondary effluent- water hyacinths	14	9.8	13 *(CBOD value)*	-1	-1	3.4	-1	-1	-1	1.4	14	-1	Asano et al., 2006 p. 109 *Constituents remaining after secondary treatment. Secondary treatment was with water hyacinths*
Secondary effluent- CAS	2-15	5-25	5.25	40-80	15-35	4-10	-1	10^4-10^5	500-700	10-30	10-40	10^1-10^3	Asano et al., 2006 p. 110 *Constituents remaining after secondary treatment. Secondary treatment was conventional activated sludge (CAS).*
Secondary effluent- CAS + filtration	0.5-4	2-8	< 5-20	30-70	15-35	4-8	-1	10^3-10^5	500-700	10-30	8-30	10^1-10^3	Asano et al., 2006 p. 110 *Constituents remaining after secondary treatment. Secondary treatment was conventional activated sludge (CAS) with filtration*
Secondary effluent- activated sludge + BNR	2-8	5-20	5-15	20-40	3-8	1-2	-1	10^4-10^5	500-700	2-8	8-20	10^1-10^3	Asano et al., 2006 p. 110 *Constituents remaining after secondary treatment. Secondary treatment was activated sludge with biological nutrient removal for the removal of nitrogen and phosphorus*
Secondary effluent- activated sludge + BR+ filtration	0.3-2	1-4	1-5	20-30	2-5	2	-1	10^4-10^5	500-700	1-5	1-5	10^1-10^3	Asano et al., 2006 p. 110 *Constituents remaining after secondary treatment. Secondary treatment was activated sludge with biological nutrient removal (for the removal of nitrogen and phosphorus) and filtration*
Secondary effluent- membrane bioreactor	1	2	<1-5	<10-30	<10	<0.3-5	-1	<100	500-700	10	0.5-5	10^0-10^3	Asano et al., 2006 p. 110 *Constituents remaining after secondary treatment. Secondary treatment was membrane bioreactor*
Secondary effluent- activated sludge + MF + RO	0.01-1	1	1	2-10	1	0.5	-1	0	5-40	1	0.1-1	0	Asano et al., 2006 p. 110 *Constituents remaining after secondary treatment. Secondary treatment was*

													activated sludge with microfiltration and reverse osmosis.
Tertiary effluent	0.5	1.3	4.3 *(CBOD value)*	-1	-1	0.1	-1	-1	-1	1.7	7.1	-1	Asano et al., 2006 p. 109 *Constituents remaining after tertiary treatment. Tertiary treatment consisted of lime precipitation and depth filtration*
AWT effluent	0.27	-1	-1	-1	-1	0.1	-1	-1	-1	0.7	0.6	-1	Asano et al., 2006 p. 109 *Constituents remaining after advanced wastewater treatment (AWT).*
…													
Industrial Wastewater													
a) Textile industry:													
Wastewater qualities of potential inputs	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**Reference/ *Comments***
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
Textile Industry-India	-1	-1	713 (500-1010)	2125 (1600-3200)	-1	-1	-1	-1	5738 (4040-7500)	354 (120-627)	-1	-1	Hussain et al. (2004) *Average Values and (ranges) from six Indian textile industries*
Textile Industry- Nigeria	-1	400 (49-1200)	332 (163-645)	1891 (1067-2430)	-1	-1	-1	-1	1181 (250-2200)	4.4 (Not detectable – 7.97)	-1	-1	Yusuff & Sonibare (2004) *Average Values and (ranges) from five Nigerian textile mills*
…													
b) Dairy industry:													
Wastewater qualities of potential inputs	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**Reference/ *Comments***
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
Dairy- Industry India	15-30	250-	350-	1500-	-1	-1	-1	-1	800-	-1	-1	-1	Sarkar, et al. (2006)

		600	600	3000					1200				*Characteristics of raw dairy wastewater of A.P. Diary in Hyderabad, India*
Dairy Industry- Cheese	-1	500-2500 *(Value for SS)*	588-5000	1000-7500	830 *(Value for TKN)*	280	-1	-1	-1	-1	-1	-1	Demirel, et al. (2005) *Ranges or mean values reported from3 cheese industry examples*
Dairy Industry- Cheese whey	-1	1780 *(Value for SS)*	-1	61000/ 68814	980/ 1462 *(Value for TKN)*	510/ 379	-1	-1	-1	-1	-1	-1	Demirel, et al. (2005) *Ranges or mean values reported from2 cheese whey industry examples*
Dairy Industry- Mixed processing	-1	340-1730/ 12500 *(Value for SS)*	-1	1150-9200/ 63100	14-272 *(Value for TKN)*	8-68	-1	-1	-1	-1	-1	-1	Demirel, et al. (2005) *Ranges or mean values reported from2 mixed dairy industry examples*
…													
c) Pulp and Paper industry:													
Wastewater qualities of potential inputs	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**Reference/ *Comments***
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
Paper mill	-1	800 *(Value for SS)*	1600	5020	11	0.6	-1	-1	-1	-1	-1	-1	Pokhrel & Viraraghavan (2004) *Typical characteristics of wastewater at paper mill*
…													
d) Brewery industry:													
Wastewater qualities of potential inputs	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**Reference/ *Comments***
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
Brewery (Beer) *Typical ranges*	-1	200-1000	1200-3600	2000-6000	25-80	10-50	-1	-1	-1	-1	-1	-1	Brito, et al. (2007)
Winery	-1	1060	8100	14150	48.2	5.5	-1	-1	-1	-1	-1	-1	Brito, et al. (2007) *Example of one wine producing*

Production: 3000 m^3/year													*industry*
Winery *Production: 6000 m^3/year*	-1	1960-5800	5540-11340	9240-17900	74-260	16-68	-1	-1	-1	-1	-1	-1	Brito, et al. (2007) *Example of one wine producing industry*
...													

References:

Brito, A.G., Peixoto, J., Oliveira, J.M., Oliveira, J.A., Costa, C.,Nogueira, R. and Rodriques, A. (2007). Chapter 7: Brewery and Winery Wastewater Treatment: Some Focal Points of Design and Operation. In: Utilization of By-Products and Treatment of Waste in the Food Industry, Oeropoulou, V. and Russ, W. (eds.), Volume 3, 2007, pp. 109-131.

Yusuff, R.O. and Sonibare, J.A. (2004). Characterization of textile industries' effluents in Kaduna, Nigeria and pollution implications. Global Nest: the Int. J., **6**(3), 212-221

Hussain, J., Hussain, I. and Arif, M. (2004). Characterization of textile wastewater. Journal of Industrial Pollution Control, **20**(1),137-144.

Sarkar, B., Chakrabarti, P.P., Vijaykumar, A. and Kale, V. (2006). Wastewater treatment in dairy industries- possibility of re-use. Desalination, **195,** 141-152.

Demirel, B., Yenigun, O. and Onay, T.T. (2005). Anaerobic treatment of dairy wastewaters: a review. Process Biochemistry, **40**, 2583-2595.

Pokhrel, D. and Viraraghavan, T. (2004). Treatment of pulp and paper mill wastewater- a review. Science of the Total Environment, **333**, 37-58.

A1.2 Recommended water quality based on guidelines (US-EPA, 2012b; WHO, 2006b)

The table below compiles water quality standards for different end-uses based on different international guidelines. The value "-1" signifies no limit specified or no data available.

US EPA guidelines, 2012

Many US states have rules, regulations or guidelines for a wide range of reclaimed water end uses and prescribe different requirements for different re-uses. Minimum suggested regulatory guidelines are presented as follows. Guidelines refer to the use of treated municipal wastewater (reclaimed water).

Remarks: Recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. The number of fecal coliform organisms should not exceed 800 CFU/100 ml in any sample.

Additional standards included for all re-use categories: pH: 6.0-9.0; Minimum CL_2 residual: 1mg/L

End-use:	Turb	TSS	BOD	COD	TN	TP	FC	TC	TDS	Nitrate	TOC	Virus	Helminths	*Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/ 100ml	CFU/ 100ml	mg/L	mg N/L	mg/L	PFU/ 100ml	eggs/L	
EPA: Urban Reuse- *unrestricted* Table 4.4, p.4-9	2	-1	10	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	*Definition: Use of reclaimed water in non-potable applications in municipal settings where public access is not restricted. Treatment: Secondary, filtration, disinfection*
EPA: Urban Reuse- *restricted* Table 4.4, p.4-9	-1	30	30	-1	-1	-1	200	-1	-1	-1	-1	-1	-1	*Definition: Use of reclaimed water in non-potable applications in municipal settings where public access is restricted by physical/institutional barriers Treatment: Secondary, disinfection*
EPA: Agricultural Reuse- *Food Crops* Table 4.4, p.4-9	2	-1	10	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	*Definition: Use of reclaimed water for surface or spray irrigation of food crops eaten raw Treatment: Secondary, filtration, disinfection*
EPA: Agricultural Reuse- *Processed food crops and Non-food crops* Table 4.4, p.4-9	-1	30	30	-1	-1	-1	200	-1	-1	-1	-1	-1	-1	*Definition: Use of reclaimed water for surface or spray irrigation of food crops processed prior to consumption and non-food crops like fodder, fiber etc. Treatment: Secondary, disinfection*
EPA: Impoundments- *unrestricted* Table 4.4, p.4-10	2	-1	10	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	*Definition: Use of reclaimed water in an impoundment in which no limitations are imposed on body contact Treatment: Secondary, filtration, disinfection*
EPA: Impoundments- *restricted* Table 4.4, p.4-10	-1	30	30	-1	-1	-1	200	-1	-1	-1	-1	-1	-1	*Definition: Use of reclaimed water in an impoundment where bod-contact is restricted Treatment: Secondary, disinfection*
EPA: Environmental Reuse	-1	30	30	-1	-1	-1	200	-1	-1	-1	-1	-1	-1	*Definition: Use of reclaimed water to create wetlands, enhance natural wetlands or sustain stream flows*

Table 4.4, p.4-10														*Treatment:* *Variable, secondary, and disinfection*
EPA: Industrial Reuse- *Once-through cooling*	-1	30	30	-1	-1	-1	200	-1	-1	-1	-1	-1	-1	*Treatment:* *Secondary*
EPA: Industrial Reuse- *Recirculating Cooling Towers* Table 4.4, p.4-10	-1	30	30	-1	-1	-1	200	-1	-1	-1	-1	-1	-1	*Treatment:* *Secondary, disinfection*
EPA: Groundwater Recharge- *Indirect potable re-use* Table 4.4, p.4-11	2	-1	-1	-1	-1	-1	0	-1	-1	-1	2	-1	-1	*Definition:* *Groundwater recharge by spreading into potable aquifers or by injection into potable aquifers and augmentation of surface water supply reservoirs* *Treatment:* *Secondary, filtration, disinfection, advanced wastewater treatment or soil aquifer treatment*

Texas water re-use standards (Example indicated in US EPA guidelines, 2012)

Remarks: *Recommended coliform limits are 30 days geometric mean values. The maximum of fecal coliform organisms in any samples is indicated in brackets.*

End-use:	Turb	TSS	BOD	COD	TN	TP	FC	TC	TDS	Nitrate	TOC	Virus	helminths	*Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/ 100ml	CFU/ 100ml	mg/L	mg N/L	mg/L	PFU/ 100ml	eggs/L	
Texas EPA: Urban Reuse- *unrestricted* Table 4.7, p.4-26	3	-1	5	-1	-1	-1	20 (75)	-1	-1	-1	-1	-1	-1	*Add. Parameter: Enterococci: 4 CFU/100mL (max. 9 CFU/100mL)*
Texas EPA: Urban Reuse- *restricted* Table 4.8, p.4-27	-1	-1	20	-1	-1	-1	200 (800)	-1	-1	-1	-1	-1	-1	*BOD: 20 mg/L without pond; 30 mg/L with pond* *Add. Parameter: Enterococci: 35 CFU/100mL (max. 89 CFU/100mL)*
Texas EPA: Agricultural Reuse-*Food Crops* Table 4.9, p.4-28	3	-1	5	-1	-1	-1	20 (75)	-1	-1	-1	-1	-1	-1	*Add. Parameter: Enterococci: 4 CFU/100mL (max. 9 CFU/100mL)*
Texas EPA: Agricultural Reuse-*Processed food crops and Non-food crops* Table 4.10, p.4-29	-1	-1	20	-1	-1	-1	200 (800)	-1	-1	-1	-1	-1	-1	*BOD: 20 mg/L without pond; 30 mg/L with pond* *Add. Parameter: Enterococci: 35 CFU/100mL (max. 89 CFU/100mL)*
Texas EPA: Impoundments- *unrestricted*	3	-1	5	-1	-1	-1	20 (75)	-1	-1	-1	-1	-1	-1	*Add. Parameter: Enterococci: 4 CFU/100ml (max. 9 CFU/100mL)*

Table 4.11, p.4-30														
Texas EPA: Impoundments-*restricted* Table 4.12, p.4-31	-1	-1	20	-1	-1	-1	200 (800)	-1	-1	-1	-1	-1	-1	*BOD: 20 mg/L without pond; 30 mg/L with pond Add. Parameter: Enterococci: 35 CFU/100mL (max. 89 CFU/100mL)*
Texas EPA: Environmental Reuse Table 4.13, p.4-32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	*Not regulated*
Texas EPA: Industrial Reuse- *Recirculating Cooling Towers* Table 4.14, p.4-33	-1	-1	20	-1	-1	-1	200 (800)	-1	-1	-1	-1	-1	-1	*BOD: 20 mg/L without pond; 30 mg/L with pond Add. Parameter: Enterococci: 35 CFU/100mL (max. 89 CFU/100mL)*
Texas EPA: Groundwater Recharge- *Indirect potable re-use* Table 4.16, p.4-35	3	-1	5	-1	-1	-1	20 (75)	-1	-1	-1	-1	-1	-1	*Add. Parameter: Enterococci: 4 CFU/100mL (max. 9 CFU/100mL)*
California water re-use standards (Example indicated in US EPA guidelines, 2012) *Remarks: Recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. (Otherwise indicated in brackets.*														
End-use:	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**helminths**	*Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/ 100ml	CFU/ 100ml	mg/L	mg N/L	mg/L	PFU/ 100ml	eggs/L	
California EPA: Urban Reuse- *unrestricted* Table 4.7, p.4-26	2	-1	-1	-1	-1	-1	-1	2.2	-1	-1	-1	-1	-1	*For media filters: 2 NTU (avg.)/ 10 NTU (max.) For membrane filters: 0.2 NTU (avg.)/ 0.5 NTU (max.) Total coliform: 240/100 ml (max.)*
California EPA: Urban Reuse-*restricted* Table 4.784, p.4-27	-1	-1	-1	-1	-1	-1	-1	23	-1	-1	-1	-1	-1	*Total coliform: 240/100 ml (max.)*
California EPA: Agricultural Reuse-*Food Crops* Table 4.9, p.4-28	2	-1	-1	-1	-1	-1	-1	2.2	-1	-1	-1	-1	-1	*For media filters: 2 NTU (avg.)/ 10 NTU (max.) For membrane filters: 0.2 NTU (avg.)/ 0.5 NTU (max.) Total coliform: 240/100 ml (max.)*
California EPA: Agricultural Reuse-	-1	-1	-1	-1	10	-1	-1	-1	-1	-1	-1	-1	-1	*Total coliforms are not specified in the Californian standards.*

Processed food crops and Non-food crops Table 4.10, p.4-29														
California EPA: Impoundments- *unrestricted* Table 4.11, p.4-30	2	-1	-1	-1	-1	-1	-1	2.2	-1	-1	-1	-1	-1	*For media filters: 2 NTU (avg.)/ 10 NTU (max.)* *For membrane filters: 0.2 NTU (avg.)/ 0.5 NTU (max.)* *Total coliform: 240/100 ml (max.)* *Supplemental pathogen monitoring*
California EPA: Impoundments-*restricted* Table 4.12, p.4-31	-1	-1	-1	-1	-1	-1	-1	2.2	-1	-1	-1	-1	-1	*Total coliform: 23/100 ml (not more than one sample exceeds this value in 30d)*
California EPA: Environmental Reuse Table 4.13, p.4-32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	*Not regulated*
California EPA: Industrial Reuse- *Once-through cooling* Table 4.14, p.4-33	2	-1	-1	-1	-1	-1	-1	2.2	-1	-1	-1	-1	-1	*For media filters: 2 NTU (avg.)/ 10 NTU (max.)* *For membrane filters: 0.2 NTU (avg.)/ 0.5 NTU (max.)* *Total coliform: 240/100 ml (max.)*
California EPA: Groundwater Recharge- *Indirect potable re-use* Table 4.16, p.4-35	2	-1	-1	-1	10 avg. of 4 consec. samples	-1	-1	2.2	-1	-1	0.5	-1	-1	*For media filters: 2 NTU (avg.)/ 10 NTU (max.)* *For membrane filters: 0.2 NTU (avg.)/ 0.5 NTU (max.)* *Total coliform: 240/100 ml (max.)* *Pathogen monitoring is not required but virus removal rates are prescribed by treatment requirements*

WHO guidelines, 2006; Vol. 2-4

The WHO guidelines for the *safe use of wastewater, excreta and greywater* (presented in 4 volumes) are designed to protect the health of farmers (and their families), local communities and product consumers. Overly strict standards may not be suitable in developing countries. The guidelines propose maximum limits or maximum ranges for E.coli and helminths in wastewater and greywater for different re-use purposes that have been set to meet health based targets (i.e. not to exceed 10^{-6} DALY per person per year).

Remarks: *Recommended standard for E.coli per 100 ml are arithmetic means and are indicated under the fecal coliform parameter in the table below. E.coli is approximately equivalent to 90% of the fecal coliforms.*

End-use:	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**helminths**	*Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	eggs/L	

WHO: Use of wastewater in agriculture-*unrestricted* Vol.2, Chapter 4.2, p.63-67	-1	-1	-1	-1	-1	-1	10^3-10^4	-1	-1	-1	-1	-1	1	*Definition: Irrigation with wastewater of all agricultural crops* *Standards for E.coli in CFU/100 mL:* *Root crops:10^3 ; Leaf crops: 10^4 ; Drip irrigation, high growing crops: 10^5*
WHO: Use of wastewater in agriculture-*restricted-highly mechanized irrigation* Vol.2, Chapter 4.2, p.67-69	-1	-1	-1	-1	-1	-1	10^5	-1	-1	-1	-1	-1	1	*Definition: Irrigation with wastewater of all agricultural crops except crops eaten unprocessed/raw (like lettuce).* *Standards for E.coli in CFU/100 mL:* *Labour-intensive irrigation: 10^4 ; High mechanized agriculture: 10^5 ; Drip irrigation, high growing crops: 10^5*
WHO: Use of wastewater in agriculture- *restricted-labour intensive irrigation* Vol.2, Chapter 4.2, p.67-69	-1	-1	-1	-1	-1	-1	10^3-10^4	-1	-1	-1	-1	-1	1	*Definition: Irrigation of all agricultural crops except crops eaten unprocessed/raw (like lettuce).* *Standards for E.coli in CFU/100 mL:* *Labour-intensive irrigation: 10^4 ; High mechanized agriculture: 10^5*
WHO: Use of wastewater in aquaculture Vol.3, Table 4.1, p.41	-1	-1	-1	-1	-1	-1	10^4-10^5	-1	-1	-1	-1	-1	1	*Standards for E.coli in CFU/100 mL:* *Consumers: 10^5 ;Workers: 10^4* *No trematode eggs detectable*
WHO: Use of grey water in agriculture-*unrestricted* Vol.4. Table 4.2, p.63	-1	-1	-1	-1	-1	-1	10^3-10^4	-1	-1	-1	-1	-1	1	*Definition: Irrigation with grey water of all agricultural crops* *Standards for E.coli in CFU/100 mL:* *High growing crops or Drip irrigation: 10^4*
WHO: Use of grey water in agriculture-*restricted* Vol.4. Table 4.2, p.63	-1	-1	-1	-1	-1	-1	10^5	-1	-1	-1	-1	-1	1	*Definition: Irrigation with grey water of all agricultural crops except crops eaten unprocessed/raw (like lettuce).*

Standards for Water Re-use in Eastern Mediterranean Region (EMR), based on WHO guidelines 1989

Reference: *A compendium of standards for wastewater reuse in the Eastern Mediterranean Region, 2006*

The compendium provides an overview of the quality standards for the reuse of treated wastewater in countries of the Eastern Mediterranean Region. The WHO in collaboration with the Arab Fund for Economic and Social Development (AFESD) recommended guidelines for wastewater (Category A-C) and greywater (Category A-C) reuse for the Eastern Mediterranean Region in 2003. In addition, Jordanian Standards for wastewater reuse are listed below (JS:893/2002).

End-use:	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**helminths**	*Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	eggs/L	
Wastewater: Category A *Untrestricted irrigation*	-1	-1	-1	-1	-1	-1	10^3	-1	-1	-1	-1	-1	0	*Definition: Irrigation with wastewater of vegetable and salad crops eaten uncooked, sport fields, public parks*

														Irrigation technique: any *Exposed group: Workers, consumers, public*
Wastewater: Category B *Restricted irrigation*	-1	-1	-1	-1	-1	-1	10^3/ 10^5	-1	-1	-1	-1	-1	0	*Definition: Irrigation with wastewater of cereal crops, industrial crops, fodder crops, pasture and trees* *Irrigation technique: spray or sprinkler (10^5 E.coli CFU/mL); Flood or furrow (10^3 E.coli CFU/mL)* *Exposed group: Workers, nearby communities*
Wastewater: Category C	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	*Definition: Localized irrigation with wastewater of crops in category B if exposure of workers and the public does not occur.* *Irrigation technique: Trickle, drip or bubbler* *Exposed group: None* *No water quality measures have to be met*
Greywater: Category A	-1	140	240	-1	-1	-1	10^3	-1	-1	-1	-1	-1	-1	*Definition: Irrigation with greywater of ornamental fruit trees and fodder crops*
Greywater: Category B	-1	20	20	-1	-1	-1	200	-1	-1	-1	-1	-1	-1	*Definition: Irrigation with greywater of vegetables likely to be eaten uncooked.*
Greywater: Category C	-1	10	10	-1	-1	-1	10	-1	-1	-1	-1	-1	-1	*Definition: Greywater used for toilet flushing*
JS:893/2002- Discharge to streams	-1	60	60	150	70	-1	10^3	-1	1500	45	-1	-1	1	*Definition: Discharge of wastewater to streams, wadis and water storage area* ***E.coli counts (FC) are given in MPN/100mL***
JS:893/2002- Groundwater recharge	2	50	15	50	45	-1	2.2	-1	1500	30	-1	-1	1	*Definition: Wastewater used for groundwater recharge* ***E.coli counts (FC) are given in MPN/100mL***
JS:893/2002- Agricultural irrigation *Group A*	10	50	30	100	45	-1	100	-1	-1	30	-1	-1	1	*Definition: Irrigation with wastewater for cooked vegetables, parking areas, playgrounds and side of roads inside cities* ***E.coli counts (FC) are given in MPN/100mL***
JS:893/2002- Agricultural irrigation *Group B*	-1	150	200	500	70	-1	10^3	-1	-1	45	-1	-1	1	*Definition: Irrigation with wastewater for plenteous trees and green areas, side of roads outside cities* ***E.coli counts (FC) are given in MPN/100mL***
JS:893/2002- Agricultural irrigation *Group C*	-1	150	300	500	70	-1	-1	-1	-1	45	-1	-1	1	*Definition: Irrigation with wastewater for field crops, industrial crops and forestry*
Water quality criteria AQUAREC, 2006														

Seven quality categories (I to VII) for different types of reuses (4 categories) are proposed and microbial and chemical limits for each category are compiled
Microbial parameters include: Total bacteria, faecal coliforms, *Clostridium perfringens*, *Legionella*, *Enterococci*, *Salmonella*, Enteroviruses, *Coliphages*, *Cryptosporidium* and *Giardia*, Nematode eggs, *T. Saginata, T.solium*

Faecal coliforms counts for microbial categories in CFU/100mL:
I: absent **II:** < 20- < 1'000 **III:** absent - < 1'000 **IV:** absent-10'000 **V:** absent - < 10'000 **VI:** <200- <10'000 **VII:** absent – 10'000
Nematode egg counts for microbial categories in eggs/L:
I: < 1-10 **II:** < 1 **III:** < 1 **IV:** < 1 **V:** < 1 **VI:** < 1 **VII:** < 1
Enterovirus counts for microbial categories in pfu/L:
I: absent – 10 **II:** absent – 10 **III:** < 1- <100 **IV:** not defined **V:** not defined **VI:** < 100 **VII:** < 1- 0.04

End-use:	Turb	TSS	BOD	COD	TN	TP	FC	TC	TDS	Nitrate	TOC	Virus	helminths	*Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	eggs/L	
AQUAREC: Private, urban irrigation *Category 1*	-1	10	10-20	100	-1	2-5	abs.-10'000	-1	1650-2400 *(3000 microS/cm)*	-1	100	abs.- < 100	<1-10	*Specific final uses (according to* ***microbial categories****):* ***I****: Residential uses* ***II****: Bathing water* ***III****: Urban uses (irrigation of landscape areas, street cleaning, fire-fighting) and unrestricted irrigation* ***IV:*** *Irrigation of industrial crops and animal fodder, restricted irrigation* ***V:*** *Irrigation of forested areas and restricted access areas* *Additional Total Kjeldahl N: 15-20 mg/L*
AQUAREC: Environmental and aquaculture *Category 2*	-1	10	10-20	70-100	-1	0.2	abs.-10'000	-1	1650-2400 *(3000 microS/cm)*	-1	70-100	< 100	<1	*Specific final uses (according to* ***microbial categories****):* ***IV:*** *Impoundments, water bodies and streams for recreational use with access (except bathing)* ***V:*** *Impoundments, water bodies and streams for recreational use with access (except bathing)* ***VI****: Surface water quality, water bodies and streams for recreational use with restricted access* *Total Kjeldahl N: 10-20 mg/L*

AQUAREC: Indirect aquifer recharge *Category 3*	-1	-1	-1	70-100	-1	-1	abs.-<10'000	-1	385-560 *(700 microS/cm)*0	25	70-100	-1	<1	*<u>Specific final uses</u> (according to microbial categories):* ***V:** Aquifer recharge by localized percolation through the soil*
AQUAREC: Industrial cooling *Category 4*	-1	10	-1	70	-1	0.2	abs.-10'000	-1	-1	-1	70	<1 - 0.04	<1	*<u>Specific final uses</u> (according to **microbial categories**):* ***VII:** Industrial cooling except for the food industry* *Total Kjeldahl N: 10 mg/L*
…														

A1.3 Local legislation from the 4 study sites considered

The table below displays water qualities included in the local legislation of Brazil, Chile, Argentinia and Mexico (based on DL2.1 and the report from Erik.).

End-use:	**Turb** NTU	**TSS** mg/L	**BOD** mg/L	**COD** mg/L	**TN** mg/L	**TP** mg/L	**FC** CFU/100ml	**TC** CFU/100ml	**TDS** mg/L	**Nitrate** mg N/L	**TOC** mg/L	**Virus** PFU/100ml	**Reference / *Comments***
BRA - Freshwater Class I	40	500	3	-1	-1	0.02	-1	-1	-1	10	-1	-1	'Standards for Wastewater Treatment in Brazil' by Marcos van Sperling, Dept. of Sanitary and Environmental Engineering, Federal University of Minas Gerais, Brazil. (http://link.springer.com/content/pdf/10.1007%2F978-3-540-31141-6_10.pdf) in: Standards for Wastewater Treatment in Brazil by Marcos von Sperling. Standards and Thresholds for Impact Assessment Environmental Protection in the European Union Volume 3, 2008, pp
BRA - Freshwater Class II	100	500	5	-1	-1	0.03	-1	-1	-1	10	-1	-1	
BRA - Freshwater Class III	100	500	10	-1	-1	0.05	-1	-1	-1	10	-1	-1	
BRA - Reuse Water Class 1	5	-1	200	-1	-1	-1	-1	200	200	-1	-1	-1	
BRA - Reuse Water Class 2	5	-1	500	-1	-1	-1	-1	500	-1	-1	-1	-1	
BRA - Reuse Water Class 3	10	-1	500	-1	-1	-1	-1	500	-1	-1	-1	-1	
BRA - Reuse Water Class 4	-1	-1	5000	-1	-1	-1	-1	5000	-1	-1	-1	-1	

End-use:	Turb	TSS	BOD	COD	TN	TP	FC	TC	TDS	Nitrate	TOC	Virus	Reference / *Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
													125-132, Springer verlag.
CHL - Drinking water for human consumption	5	-1	-1	-1	-1	-1	-1	-1	-1	10	-1	-1	(page 61 of Del.2.1 gives information about water quality standards in Chile); Decrete number NCh 1333 defines water quality standards for esthetic use, irrigation of public areas and agricultural areas. NCh 409 defines the water quality standard for drinking water. Numbers in this table are based on NCh 1333 and NCh 409.
CHL - Water for agricultural Irrigation	-1	-1	-1	-1	-1	-1	-1	1000	5000	-1	-1	-1	
CHL - Water for surface water or groundwater recharge	30	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
End-use:	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**Reference / *Comments***
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
ARG - Drinking water for human consumption	5	-1	-1	-1	-1	-1	0	-1	1000	-1	-1	-1	(page 142 of Del.2.1 gives information about water quality standards for irrigation in Agriculture (for non-food crops) in Argentina); 'Portaria 518-2004' is the standard for Drinking Water Quality in Argentina.
ARG - Water for agricultural Irrigation(non-food crops)	-1	50	30	-1	30	5	-1	-1	500	30	-1	-1	
End-use:	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**	**Reference / *Comments***
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
MEX - Drinking water for human consumption	5	-1	-1	-1	-1	-1	-1	2	1000	10	-1	-1	(page 97 of Del.2.1 gives AN OVERVIEW of the water

End-use:	Turb	TSS	BOD	COD	TN	TP	FC	TC	TDS	Nitrate	TOC	Virus	Reference / *Comments*
	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	
MEX - Water for public service with direct contact	20	-1	20	-1	-1	-1	240	-1	-1	-1	-1	-1	quality standards for irrigation in Agriculture, urban reuse, recreational use, environmental reuse, industrial reuse, groundwater recharge and potable reuse in Mexico); the standards listed below give an overview of the corresponding fields
MEX - Water for public service without direct contact	30	-1	30	-1	-1	-1	1000	-1	-1	-1	-1	-1	

A1.4 COROADO Water Quality Classes for re-use for Latin America

The table below proposes water quality classes for Latin America based on the present local regulations in the Countries Brazil, Argentina, Chile and Mexico and re-use guidelines (i.e. US-EPA, WHO, AQUAREC) as well as re-use standards from other countries (i.e. Water re-use standards Jordan). The classes are divided according to the type of intended re-use: Class A = Residential uses; Class B = Urban re-use and unrestricted irrigation, Class C = Environmental and restricted irrigation; Class D = Industrial re-use and Class E = Groundwater recharge.

Class	Description	Turb	TSS	BOD	COD	TN	TP	FC	TC	TDS	Nitrate	TOC	Virus	Helminths
		NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	mg/L	mg N/L	mg/L	PFU/100ml	eggsL
Class A	**A = Residential uses** *Water can be reused for residential uses such as toilet flushing, gardening, car washing*	**5**	**10**	**10**	**100**	**-1** **TKN: 15-20 Ammonium N: 2-20**	**2-5**	**0**	**$<10^3$**	**200-500**	**10**	**100**	**<10**	**<1**
Class B	**B = Urban re-use and unrestricted irrigation** *Water can be reused for bathing water, urban purpose such as irrigation of landscape areas, street cleaning, firefighting and*	**10**	**10**	**20**	**100**	**-1** **TKN: 15-20 Ammonium N: 2-20**	**2-5**	**$<10^3$**	**$<10^4$**	**1650-2400** ***(3000 microS/cm***	**30**	**100**	**<10**	**<1**

	unrestricted irrigation for agricultural purposes													
Class C	**C = Environmental and restricted irrigation** *Water could be reused for restricted agriculture* *Discharge to streams…*	**10**	**50**	**30**	**70-100**	**30**	**0.2**	**$<10^4$**	**$<10^5$**	**1650-2400** ***(3000 microS/cm***	**45**	**70-100**	**<100**	**<1**
Class D	**D = Industrial re-use.**	**-1**	**10**	**30**	**70**	**-1**	**0.2**	**$<10^4$**	**$<10^4$**	**-1**	**-1**	**70**	**<1**	**<1**
Class E	**E= Groundwater recharge (indirect potable re-use)**	**2**	**50**	**15**	**70-100**	**10**	**-1**	**$<10^4$**	**$<10^5$**	**385-560** ***(700 microS/cm)***	**25**	**70-100**	**-1**	**<1**

Coroado water quality classes (still under development)

Class	**Description**	**Turb**	**TSS**	**BOD**	**COD**	**TN**	**TP**	**FC**	**TC**	**TDS**	**Nitrate**	**TOC**	**Virus**
		NTU	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 ml	CFU/100 ml	mg/L	mg N/L	mg/L	PFU/100 ml
Class A	**A** = Water quality is **very low**. *Water cannot be reused for any purpose nor discharged and needs treatment.*	2	10	10	-1	10	-1	0	-1	-1	-1	-1	25
Class B	**B** = Water quality is **low**. *Water cannot be reused for any purpose but can be discharged according to the national regulations.*	-1	20	20	150	-1	-1	-1	1000	30	50	-1	-1
Class C	**C** = Water quality is **medium**. *Water could be reused for restricted agricultural (food crops not consumed uncooked) and/or*	10	30	30	-1	10	-1	200	23	-1	-1	-1	-1

	industrial purposes.												
Class D	**D** = Water quality is **good**. *Water could be reused for agriculture and other non-potable uses in industry or in the urban network.*	-1	150	300	500	70	-1	-1	-1	-1	45	-1	-1
Class E	**E** = Water quality is **excellent**. *Water could be reused for potable uses.*	-1	30	30	-1	-1	-1	200	-1	-1	-1	-1	-1

Appendix II Unit Processes Factsheets

Preliminary treatment

Process description: The first steps in the treatment of municipal wastewater include usually flow measurement, screening, pumping and grit removal. Flow measuring is essential for all wastewater and water reuse treatment plants and is commonly done by a Parshall flume, which allows the calculation of volumetric flow rates based on the height of the water head in a specially designed channel.

Bar screens.

Bar screens are typically at the entrance of a wastewater treatment plant (WWTP) and used to remove large objects such as rags, plastics bottles, diverse floatables and solids from the waste stream entering the treatment plant. They have openings of 1 to 6 cm (Hammer & Hammer, 2012) and collected solids can be removed by a traveling rake (Figure 5). Typically bar screens fall under two classification, *mechanical bar screens* and *manual bar screens* (trash racks can either be manually cleaned or mechanically cleaned). There are various types of bar screens available for installation, they include but not limited to *chain bar screens*, *reciprocating rake bar screens*, *catenary bar screens*, and *continuous belt bar screens* (e.g. Infobarscreens, 2013).

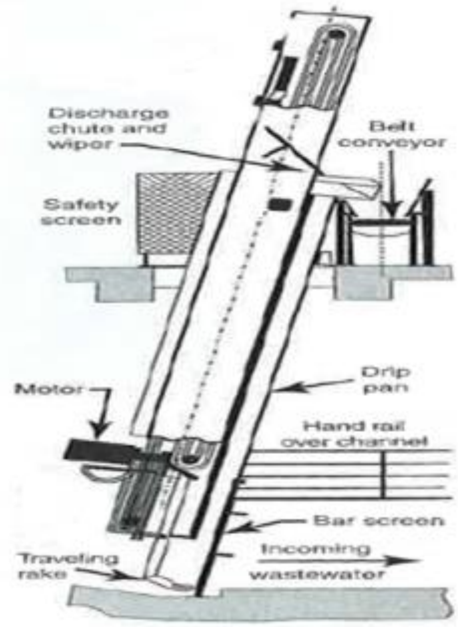


Figure 5 Mechanically cleaned bar screen with traveling rake (Hammer and Hammer 2012)

Screening.

In order to remove greater quantities of papers, plastic etc. perforated plates or filter belts can be used to screen influent waste water. Coarse screen types have openings of 6 mm or larger, finer screens approximately 1.5 to 6 mm (US-EPA, 1994). Applications that typically use fine screens are pre-treatment in conjunction with a coarse bar screen, primary treatment instead of primary clarifiers, and pre-treatment at combined sewer overflows. When clogging of trickling filters presents the potential for a problem, it is common to use fine screens upstream of the trickling filters to remove solids from the primary effluent (Infobarscreens, 2013). The finer screens are required if non-biodegradable fibrous material and hair have to be removed (Hammer & Hammer, 2012). Cleaning of the screens can be by brush, water spray or a combination of the two. In most cases, periodic cleaning of brushes by plant staff is required. Fine screen units can be installed instead of bar screens or in series with bar screens. Series of progressively finer screens can help reduce organic load (Hammer & Hammer, 2012). The fine screens that are used in pre-treatment and primary treatment are: Band Screens (effective for fine screening applications that have high flows), Static Wedgewire Screens (typically installed in smaller treatment plants), Rotary Drum Screens (effective for applications that require big solids separation and small energy usage), and Step Screens (cost effective solids separation).

Advantages: Protection of membranes in tertiary treatment; very low equipment maintenance (manually cleaned screens); mechanically cleaned screens have lower labor costs than manually cleaned screens
Disadvantages: Head loss (ranges between 0.8 to 1.4 m)
Pre-treatment: Bar screens or raw waste water

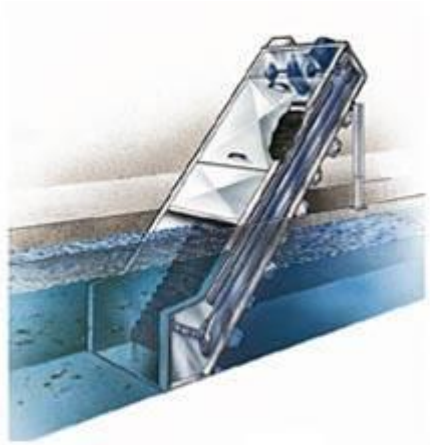


Figure 6: The tangential flow screen utilizes the natural motion of the water to screen and collect particles (source: Infobarscreens 2013)

Grit Chamber.

In order to remove greater quantities of papers, plastic etc. perforated plates or filter belts can be used to screen influent waste water. Coarse screen types have openings of 6 mm or larger, finer screens approximately 1.5 to 6 mm (EPA, 1994). Applications that typically use fine screens are pre-treatment in conjunction with a coarse bar screen, primary treatment instead of primary clarifiers, and pre-treatment at combined sewer overflows. When clogging of trickling filters presents the potential for a problem, it is common to use fine screens upstream of the trickling filters to remove solids from the primary effluent (Infobarscreens, 2013). The finer screens are required if non-biodegradable fibrous material and hair have to be removed (Hammer & Hammer, 2012). Cleaning of the screens can be by brush, water spray or a combination of the two. In most cases, periodic cleaning of brushes by plant staff is required. Fine screen units can be installed instead of bar screens or in series with bar screens. Series of progressively finer screens can help reduce organic load (Hammer & Hammer, 2012). The fine screens that are used in pre-treatment and primary treatment are: Band Screens (effective for fine screening applications that have high flows), Static Wedgewire Screens (typically installed in smaller treatment plants), Rotary Drum Screens (effective for applications that require big solids separation and small energy usage), and Step Screens (cost effective solids separation).

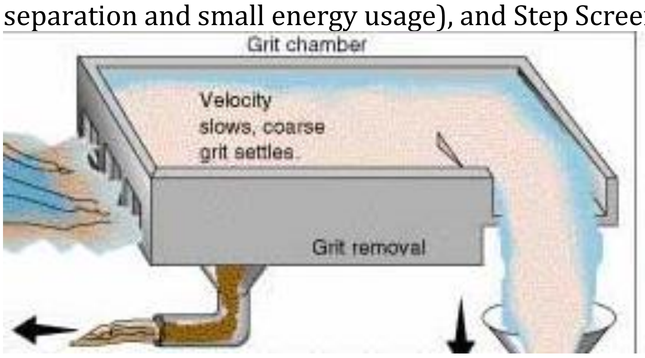


Figure 7: Raw sewage moves from the grit chamber to primary treatment (source: homestead, 2013)

Advantages: Protection of downstream processes from increased abrasion; prevention of clogging; aerated grit chambers have consistent removal efficiencies over a wide range of flows and aeration may reduce septic conditions and thus increase the performance of downstream

unit processes, vortex type grit chambers remove a high percentage of fine grit, have consistent removal efficiencies over a wide range of flows and a small footprint and the headloss is very small; detritus tanks do not require flow control and headloss is minimal; horizontal flow grit chambers are flexible and simple to construct; hydrocyclones remove grit and suspended solids and may ideally remove as many solids as a primary clarifier (US-EPA, 1994)
Disadvantages: Increased headloss could in some cases require additional pumping; aerated grit chambers can emit volatile organics and odours and require more power than other grit removal processes; vortex-type systems often require deep excavation due to their height and clogging can be an issue; detritus tanks are not easily adjustable to varying flow and large quantities of organic material is removed, thus requiring washing and classifying of grit; horizontal flow grit chambers are not easily adjustable to varying flow, remove excessive amounts of organic matter if flow is not effectively controlled and have massive head loss; hydrocyclones require energy since they use pumps (US-EPA, 1994)
Pre-treatment: Bar screens and/or coarse and fine screens

Equalization tank.

Wastewater received at many WWTPs can vary considerably in volume and level of pollution. Therefore may WWTPs have to install equalization tanks, in which wastewater is stored for a certain period of time prior to treatment in order to generate a stable flow (Figure 8). Besides equalizing of waste water flow (volume per time), equalization basins also provide a more stable quality of influent waste water. Both aspects are important to maximize the efficiency of downstream processes and to control their operation. Equalization tanks are usually equipped with agitators or aerators for mixing and prevention of settling of suspended solids.

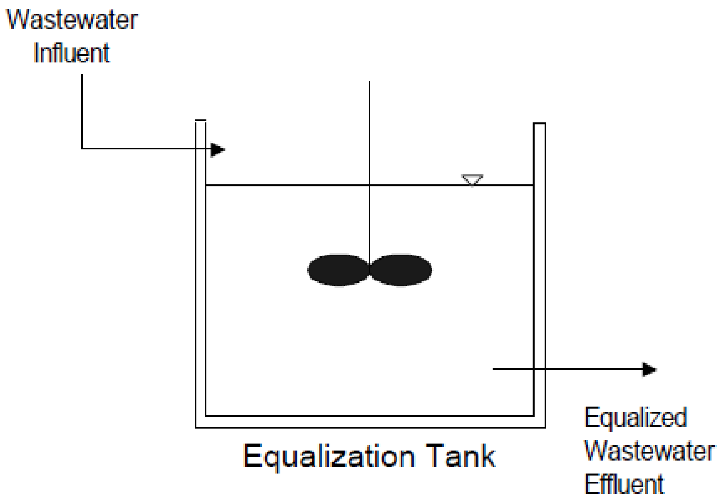


Figure 8 Diagram of a typical equalization tank, source: EPA (1996)

Sedimentation without coagulant

All waters contain dissolved and suspended particles. Sedimentation is one of the processes used to separate the suspended solids portion from the water. Sedimentation (settling) tanks that receive wastewater prior to biological process units are called primary clarifiers (Figure 9). In these tanks, sewage is separated into settled sewage and sludge by providing quiescent, slow motion flow conditions. The sedimentation performance is related to the effective surface area and greater suspended solids removal performance can be achieved by plate separator sedimentation systems. In these systems, inclined parallel plates divide the tank into integral sections in which particles settle and slide to a sludge collector (hopper) at the bottom (Bryan, Chambers, & Cooper, 1995). Sludge is periodically removed from the hopper for disposal. The effectiveness of sedimentation depends heavily on the type of wastewater supplied and whether contaminants are dissolved or suspended. While for instance for municipal wastewater BOD may be largely from dissolved organics and BOD removal below 20 %, the removal efficiency can be up to 60 % for some industrial wastewaters containing more suspended solids. Rectangular tanks are usually used where space is limited. However, circular basins are generally preferred in new construction because of improved performance and lower maintenance costs (Hammer & Hammer, 2012).

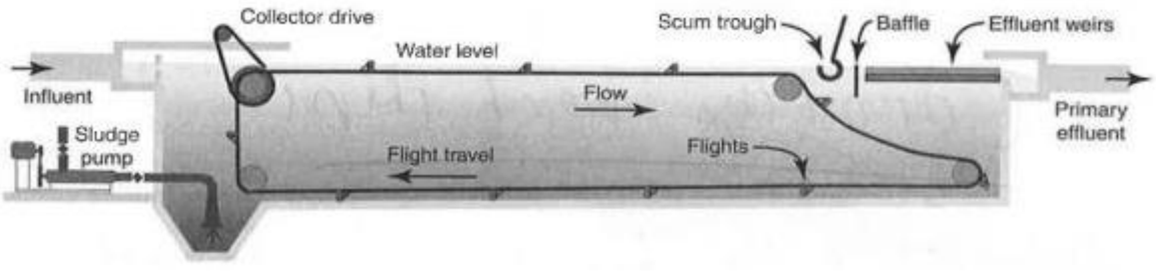


Figure 9 Longitudinal section of a rectangular primary clarifier. Settled solids are moved to the sludge pump at the influent end of the clarifier and floating matter to a scum through, where it is removed by pumping (source: Hammer and Hammer 2012)

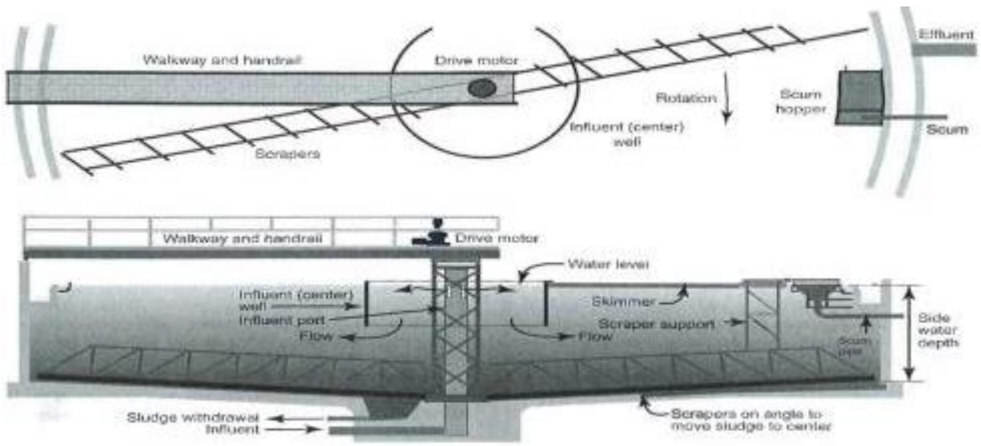


Figure 10 Partial plan view (above) and section through (below) circular primary clarifier (source: Hammer and Hammer 2012)

Advantages: No chemicals required
Disadvantages: Low efficiencies for dissolved contaminants; efficiencies highly dependent on influent wastewater composition
Pre-treatment: Preliminary treatment (bar screens; fine screens); raw wastewater can be applied

Sedimentation with coagulant

Process description: Coagulation, flocculation and sedimentation occur in successive steps: coagulation destabilizes the particle's charges by using for example ferric chloride (FeCl3) or alum (Al2(SO4)3). After neutralisation of the charges, the small particles can stick together in so called "microflocs". The coagulation process usually lasts 1-3 minutes with strong and rapid mixing. The second step, flocculation, occurs afterwards with gentle mixing and the microflocs particle size increase to visible suspended particles. When the particles reach an optimal size and a good strength, the sedimentation step can start. This method can be used to reduce loads for subsequent biological unit processes and temporarily avoid the expansion of secondary treatment units and is also used in some cases to remove suspended solids before discharge into oceans. In addition, a polymer with a high molecular weight can enhance flocculation and solid capture (Hammer & Hammer, 2012).

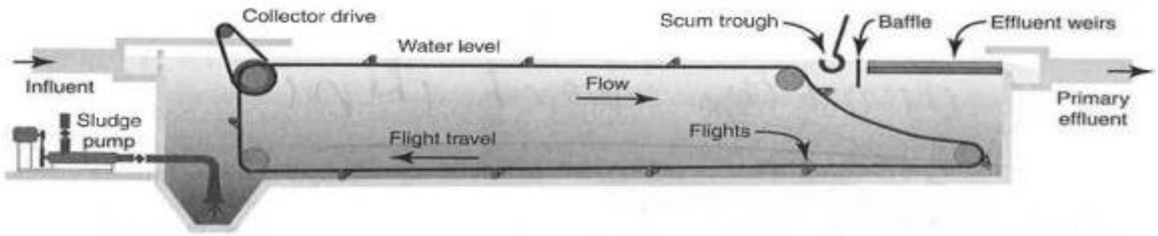


Figure 11 Longitudinal section of a rectangular primary clarifier. Settled solids are moved to the sludge pump at the influent end of the clarifier and floating matter to a scum through, where it is removed by pumping (source: Hammer and Hammer 2012)

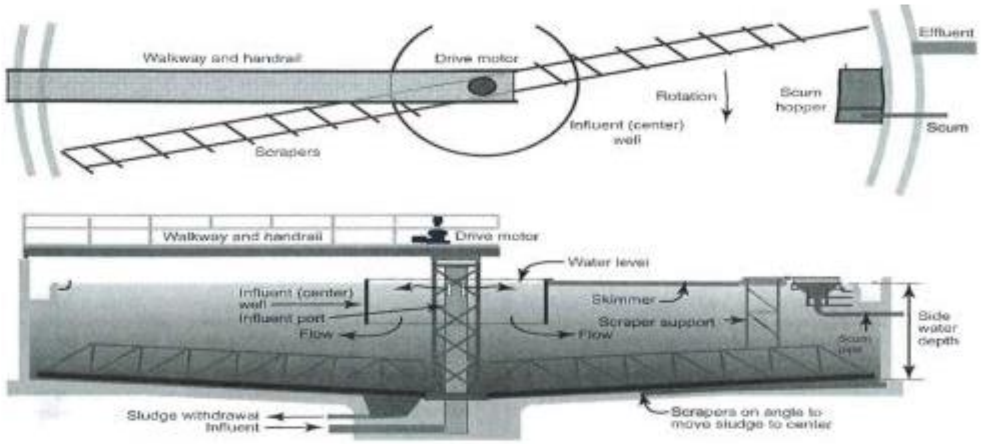


Figure 12 Partial plan view (above) and section through (below) circular primary clarifier (source: Hammer and Hammer 2012)

Advantages: Compared to sedimentation without coagulant higher suspended solid removal rates and therewith related parameters of removal efficiencies (BOD, COD etc.); adaptability to varying flow
Disadvantages: Higher power and chemical demand compared to sedimentation without coagulant; higher cost and sludge production compared to sedimentation without coagulant
Pre-treatment: Preliminary treatment (bar screens; fine screens); raw wastewater can be applied

Anaerobic stabilization ponds

Waste Stabilization Ponds (WSP), often referred to as oxidation ponds or lagoons, are holding basins used for secondary wastewater (sewage effluents) treatment where decomposition of organic matter is processed naturally, i.e. biologically. The activity in the WSP is a complex symbiosis of bacteria and algae, which stabilizes the waste and reduces pathogens. Stabilization ponds can be classified as aerobic, aerated, anaerobic and facultative ponds according to the type of biological activity taking place in them (Figure 13).
See processes **S5** and **S6** for more information on facultative and aerobic stabilization ponds.

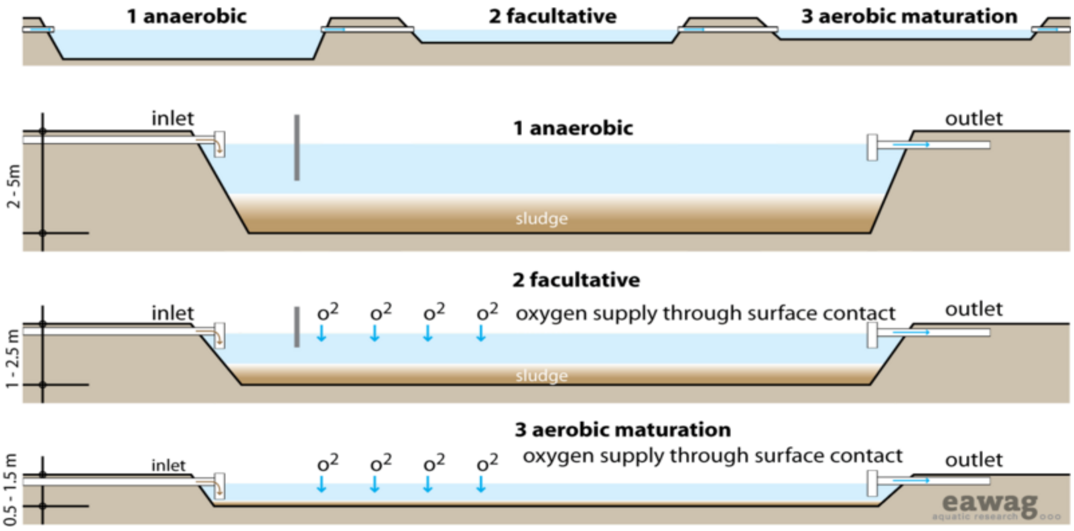


Figure 13 Cross section through a possible sequence of maturation ponds (upper panel), an anaerobic pond (second panel), a facultative pond (third panel) and an aerobic pond (lower panel), source: Sandec & EAWAG (2013)

Activated sludge processes

A variety of processes, designs and mechanisms exist for wastewater treatment using activated sludge. The processes use dissolved oxygen to promote the growth of microorganisms that substantially remove organic material (US-EPA, 2004b). Activated sludge treatment refers to the suspension of microorganisms in the wastewater, which accelerates natural biological oxidation processes and effectively removes soluble and also some insoluble pollutants from the water (Landcom, 2006). The wastewater is supplied with air, providing oxygen for microbial degradation of wastewater organics (14). Anoxic zones can be added, in which nitrate (instead of oxygen) is used to oxidise organic matter. In this case, nitrogen gas (N_2) is produced. Activated sludge has primarily been used to reduce the Biological Oxygen Demand (BOD) and suspended solids (TSS) from wastewaters. There is a high number of different designs, which may in addition provide reduction of total nitrogen and other variables. Settling tanks following biological treatment (secondary sedimentation) are similar to primary clarifiers (P3).

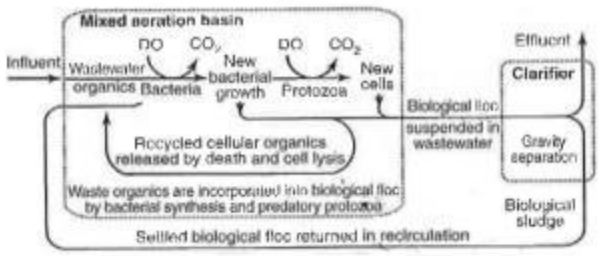


Figure 14 Schematic representation of the activated sludge process followed by secondary sedimentation (clarifier), source: Hammer and Hammer 2012

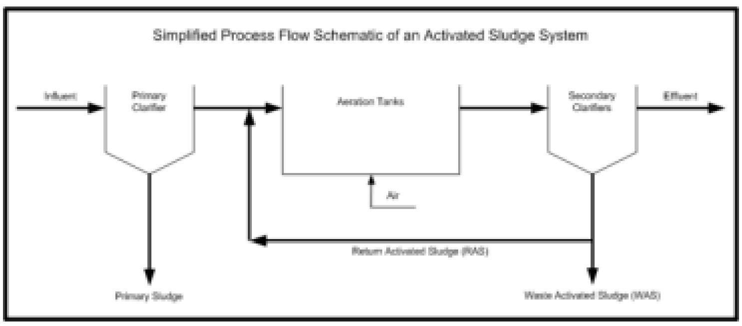


Figure 15 Simplified process flow schematic of an activated sludge system (source: www. waterfacts.net)

Pre-treatment: Primary treatment

Low Loaded Activated Sludge w/o de-N + Sec Sedim.
After entering a tank the sewage gets mixed with microorganisms and dissolved oxygen for microbial degradation of wastewater organics. The low loaded activated sludge process shows a F/M ratio 0.2-0.5 (BOD/day)/(MLSS) and a sludge age of 5-15 days. For a process without de-nitrification is no anoxid zone added. Settling tanks following biological treatment (secondary sedimentation) are similar to primary clarifiers (P3).

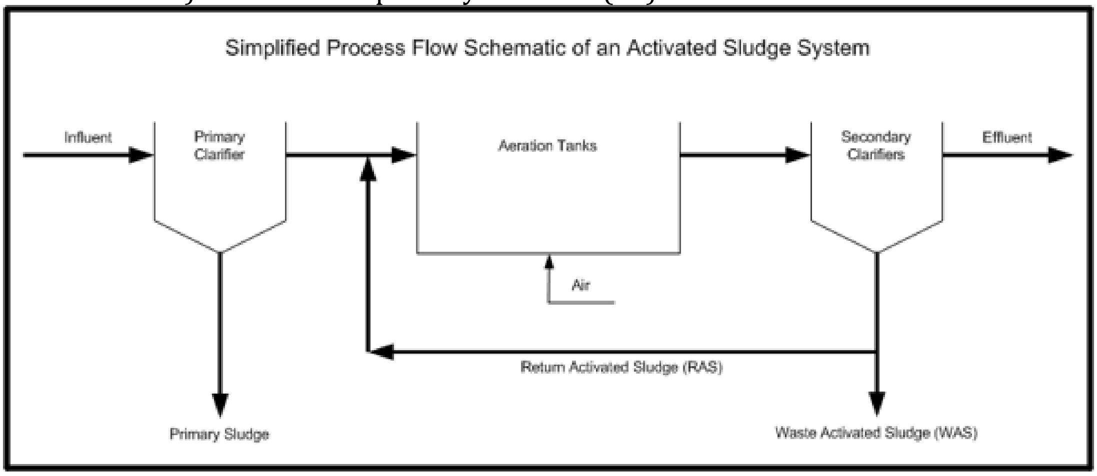


Figure 16 Simplified process flow schematic of an activated sludge system (source: www. waterfacts.net)

Advantages: No chemicals needed (Aquarec, 2005).
Disadvantages: High power requirements (Aquarec, 2005)
F/M ratio (Food to Mass Ratio): Important parameter in the activated sludge process. It describes the relation between the BOD and MLSS.
BOD (Biological Oxygen Demand): Bacterial Food
MLSS (Mixed Liquor Suspended Solids): Amount of biomass in the reactor (Meniscus).
Pre-treatment: Primary Treatment

Low Loaded Activated Sludge w de-N + sec. Sedim.
After entering a tank the sewage gets mixed with microorganisms and dissolved oxygen for microbial degradation of wastewater organics. The low loaded activated sludge process shows a F/M ratio 0.2-0.5 (BOD/day)/MLSS and a sludge age of 5-15 days. (Hammer & Hammer, 1996) In the anoxic zone, nitrate is used by facultative bacteria to oxidize BOD by releasing nitrogen gas (N2). Settling tanks following biological treatment (secondary sedimentation) are similar to primary clarifiers (P3).

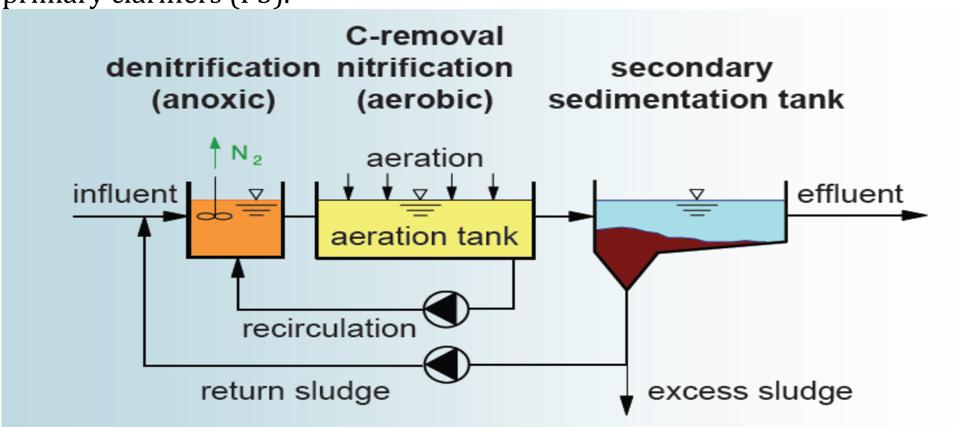


Figure 16 Process Chart Low Loaded activated Sludge w de-N + sec. Sedimentation
(Prof. H Kroiss, Institute for Water Quality, Resource and Waste Management Vienna University of Technology, 2008)

Advantages: No chemicals needed (Aquarec, Design Support software for Waterreuse, 2005)
Disadvantages: High power requirements (Aquarec, Design Support software for Waterreuse, 2005)
Pre-treatment: Primary Treatment

High Loaded Activated Sludge + Sec. Sedim.

The difference between High Loaded Activated Sludge and Low Loaded Activated Sludge is the F/M ratio. The F/M ratio for High loaded activated sludge is 0.5-1.0 ((BOD/day)/(MLSS)). The sludge age is 3-10 days (Hammer & Hammer, 1996). Settling tanks following biological treatment (secondary sedimentation) are similar to primary clarifiers (P3).

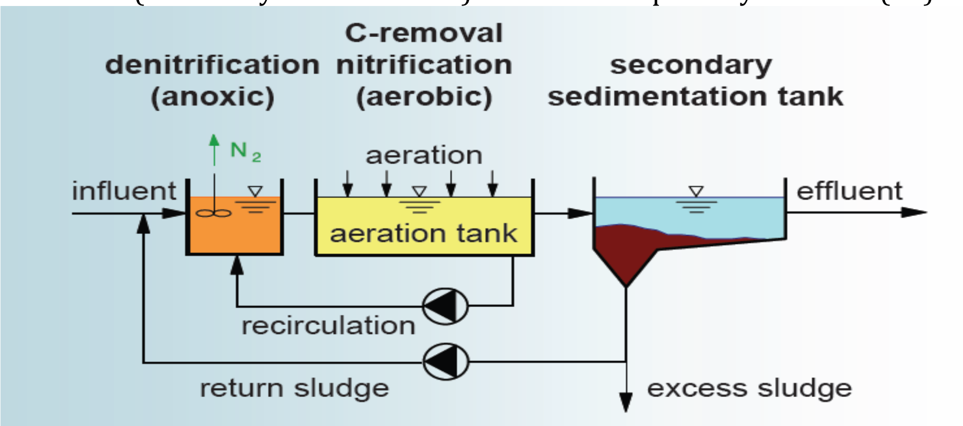


Figure 17 Process Chart Low Loaded activated Sludge w de-N + sec. Sedimentation
(Prof. H Kroiss, Institute for Water Quality, Resource and Waste Management Vienna University of Technology, 2008)

Advantages: Less energy and no chemicals needed (Aquarec, Design Support software for Waterreuse, 2005)
Disadvantages: Higher sludge production (Aquarec, Design Support software for Waterreuse, 2005)
Pre-treatment: Primary Treatment

Extended aeration

The extended aeration process is a modified activated sludge process. It includes the removal of biodegradable organic wastes under aerobic conditions. Air and mixing must be supplied by aeration or mechanical. Important for the biological growth is the pH and the concentration of essential nutrients (EPA, Technology Fact Sheet, Package Plants, 2000). The extended aeration process shows a F/M- Ratio 0.05-0.2(BOD/day)/MLSS and a sludge age older than 20 days. (Hammer & Hammer, 1996)

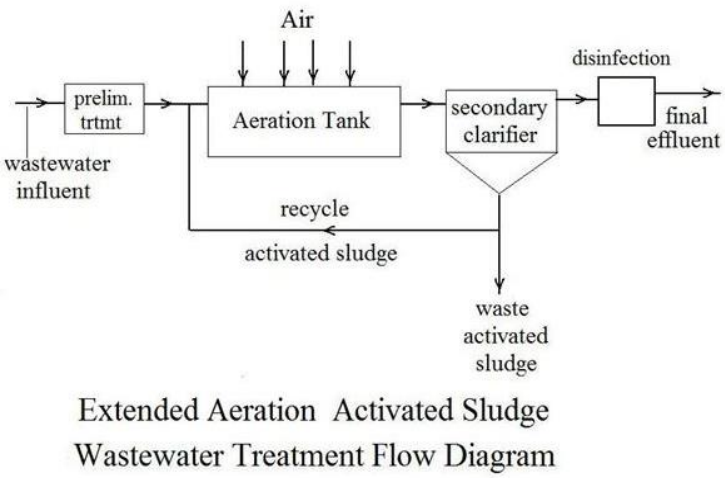


Figure 18 Abb. 3 Process Chart Extended Aeration
http://img.bhs4.com/f9/0/f90796138ced74db3e9027a3c7fff6a386ef981b_large.jpg (Stand 18.12.2013)

Advantages: Easy to operate, don't require a primary sedimentation (EPA, Technology Fact Sheet, Package Plants, 2000)
Disadvantages: No de-nitrification, requires more energy, needs more space and tankage (EPA, Technology Fact Sheet, Package Plants, 2000).

Trickling filter with secondary sedimentation

In contrast to activated sludge systems (S1-S3), the microorganisms used for the cleaning process are attached to a medium (attached-growth process). The microorganisms build a biological film or slime layer of 0.1 to 0.2 mm thickness and include aerobic, anaerobic and facultative bacteria, fungi, algae and protozoa (EPA, 2000a). Microorganisms from the wastewater attach to the medium and successively increase the thickness of the biological film. As the film thickness increases, oxygen supply to layers closer to the filter decreases and anaerobic processes dominate. With increasing film thickness, microorganisms cannot attach any more portions of the film fall of the medium (called sloughing) and need to be removed by a secondary sedimentation system.

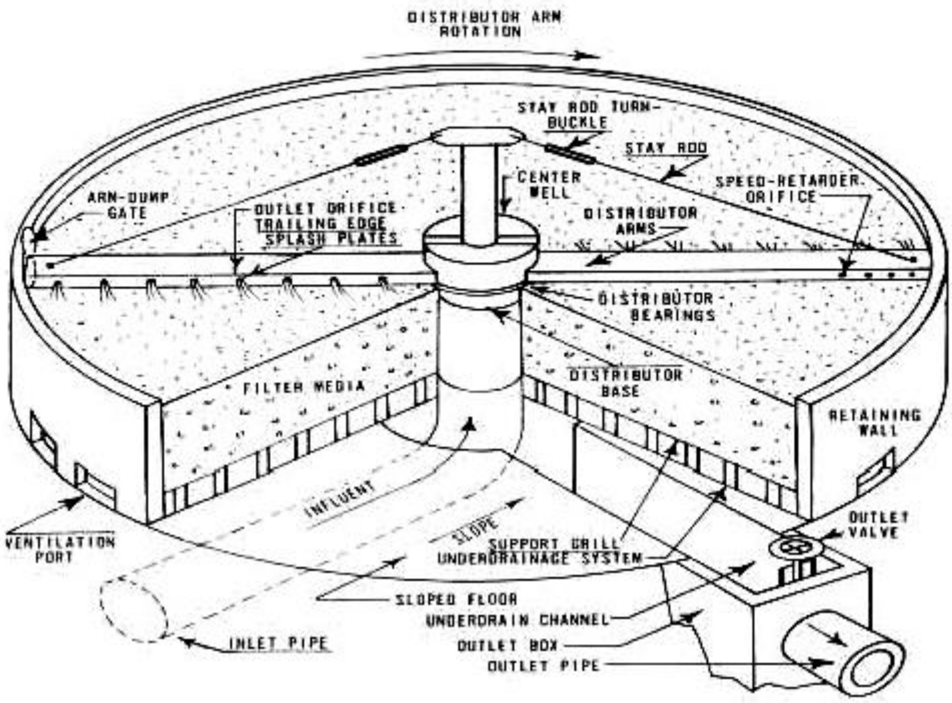


Figure 19 Typical trickling filter (source: EPA 2000b)

Advantages: Simple design; durable elements; moderate power demand; moderate skills needed for O&M.
Disadvantages: Depending on type of water reuse and local regulations, additional treatment may be required; clogging and excess biomass accumulation, impairing oxygen supply, can occur; flexibility more restricted compared to activated sludge systems; more odour intensive than activated sludge systems; aquatic snails may be a problem
Pre-treatment: Preliminary treatment

Rotating biological contactor (RBC)

The Rotating Biological Contactor (RBC) process is a fixed film wastewater treatment technology used in municipal or industrial wastewater treatment. The unit consists of a round steel or plastic media on a horizontal shaft in a concrete tank. The media is slowly rotated in the wastewater and approximately 40 % of the media are submerged in wastewater (Figure 14).

Microorganisms biologically degrading organic pollutants attach on the rotating media and form a fixed film of thin biomass layer. By rotating into the air, oxygen can be absorbed by the microorganisms. Excess biomass continuously falls off the media and is removed in a subsequent secondary clarifier (USFilter, n.d.).

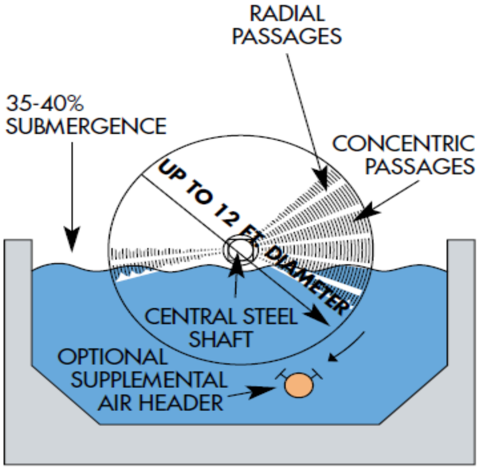


Figure 20 Diagram of a rotating biological contactor process (source: USFilter)

Advantages: Minimal maintenance; low energy demand
Pre-treatment: Primary treatment

Stabilization ponds: Aerobic, aerated and facultative

Waste Stabilization Ponds (WSP), often referred to as oxidation ponds or lagoons, are holding basins used for secondary wastewater (sewage effluents) treatment where decomposition of organic matter is processed naturally, i.e. biologically. The activity in the WSP is a complex symbiosis of bacteria and algae, which stabilizes the waste and reduces pathogens. Stabilization ponds can be classified as aerobic, aerated, anaerobic and facultative ponds according to the type of biological activity taking place in them (21).

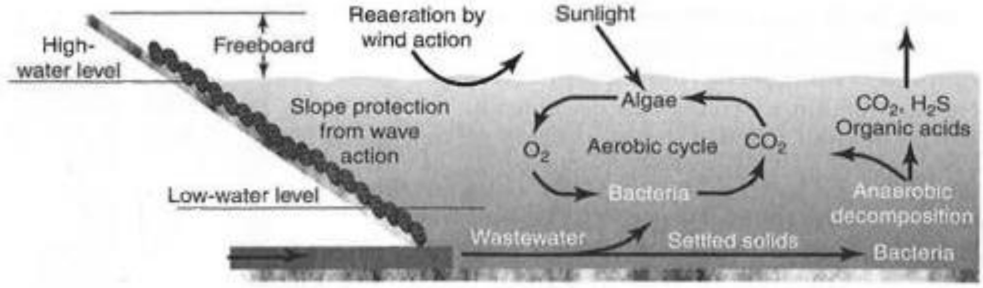


Figure 21 Cross section of a facultative stabilization pond showing biological reactions of bacteria and algae (source: Hammer and Hammer 2012)

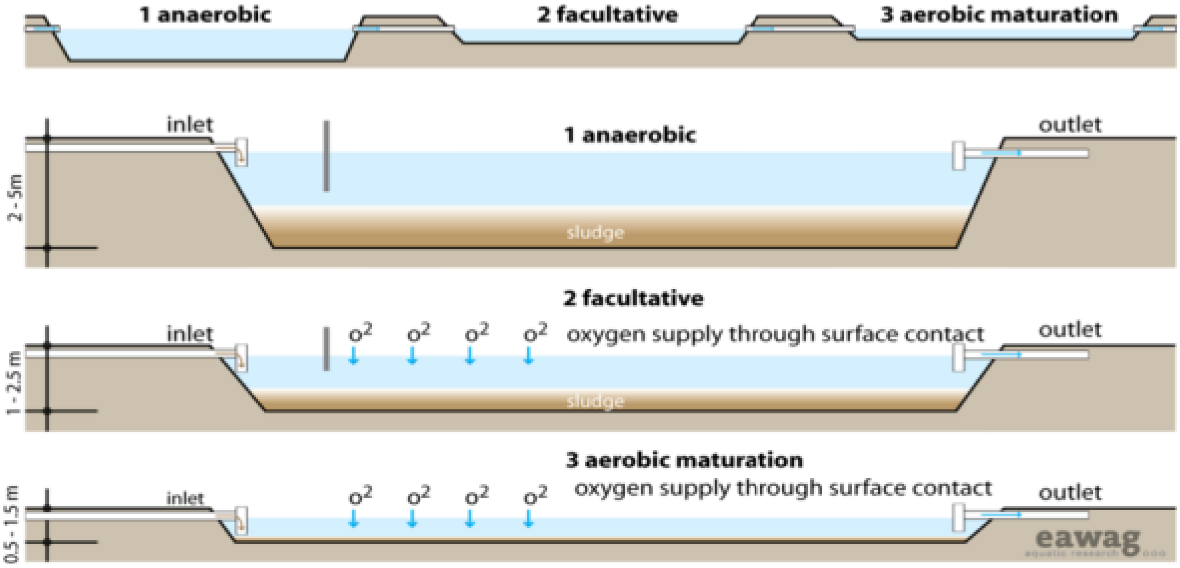


Figure 22: Cross section through a possible sequence of maturation ponds (upper panel), an anaerobic pond (second panel), a facultative pond (third panel) and an aerobic pond (lower panel), source: Sandec & EAWAG (2013)

Membrane bioreactor (MBR)

A membrane bioreactor (MBR) is a combination of biological activated sludge processes with low pressure membrane technology (microfiltration/ultrafiltration) where the membranes provide a barrier to suspended solids. The membranes provide clarification and filtration functions. The reactor is operated similar to activated sludge processes (S1-3), but without the need of secondary clarification and replacing some tertiary unit processes such as sand filtration. MBRs can have to basic configurations (Figure 23) with either submerged membranes (permeate) or external circulation (Ravazini et al., 2006).

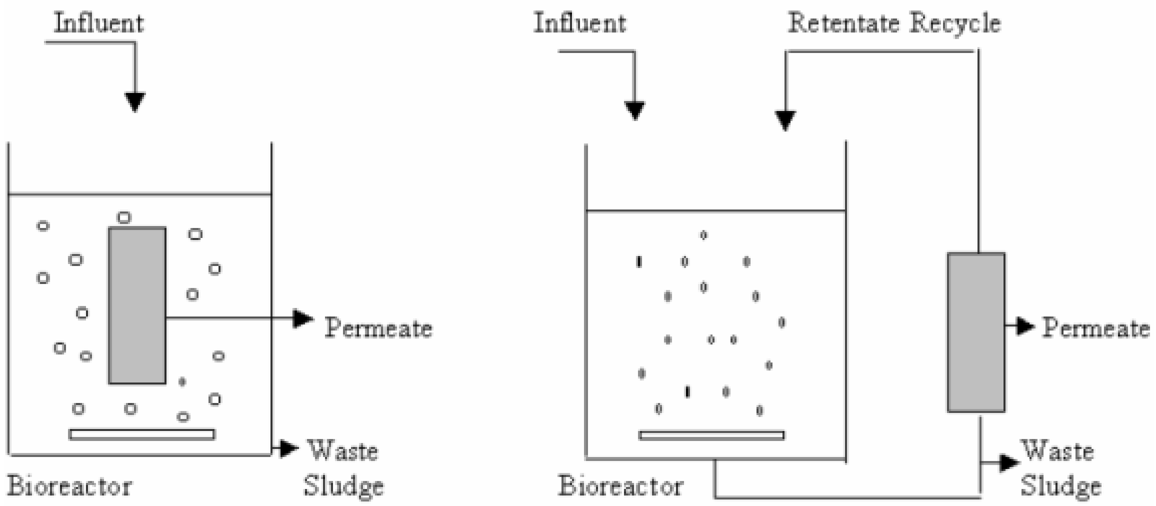


Figure 23: Two main configuration of MBR systems: submerged membrane (left panel) and external configuration (side stream, right panel), source: Ravazini et al. (2006)

Advantages: Very high-quality effluent, increased process stability (due to increased MLSS and decreased F/M ratio); small size (membranes replace clarifier and conventional filters); flexible extension of existing WWTPs is possible
Disadvantages: Operation cost (membrane life and replacement cost); energy demand of membrane pumps; increased sludge return (Hammer & Hammer 2012)

Constructed: subsurface and free-water-surface flow

Most wetlands for wastewater treatment are free water systems in which the water surface is exposed to the atmosphere and include bogs, swamps and marshes. Subsurface flow wetlands (Figure 24, left panel) are specifically designed for treatment or polishing of different types of wastewater. Subsurface wetlands can be constructed as beds or channels with appropriate media, commonly gravel in the U.S. and Europe, and are planted with vegetation typical for marshes (grasses and emergent aquatic plants). In the subsurface flow system, odours, mosquito infestations and risk of public contact can be efficiently controlled, while in free-water surface systems (Figure 24, right panel) mosquitoes and public access are concerns (EPA, 2000b).

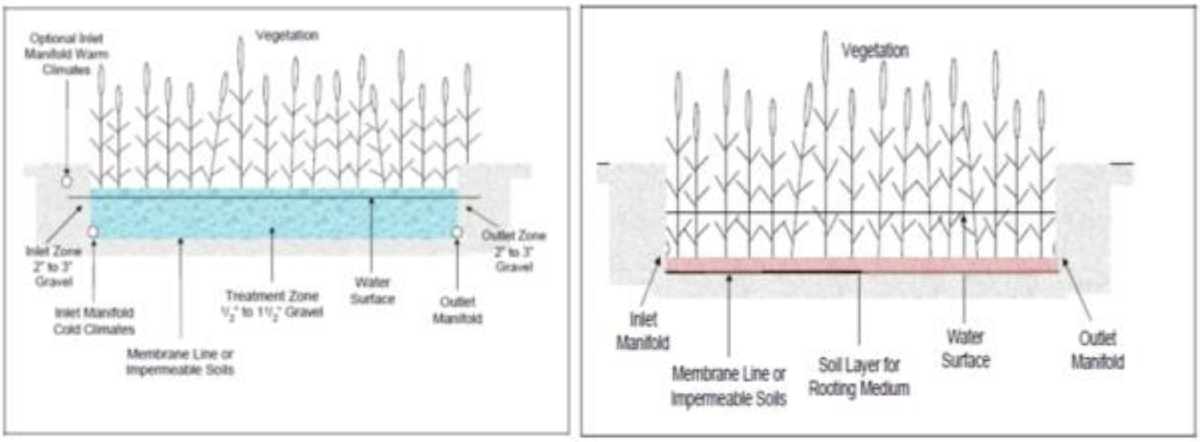


Figure 24 Subsurface constructed wetland (left panel, source: EPA 2000a) and free-water-flow constructed wetland (right panel, source: (EPA 2000a)

Advantages: Minimum equipment, power and operator needs; very low sludge production; subsurface flow wetlands: effective and reliable for BOD, COD, TSS, metal and some persistent organics removal (US-EPA, 2000d)
Disadvantages: Large land requirement; phosphorus, metals and some persistent organic compounds accumulate in the sediments; lower removal rates during winter in cold climates

Constructed wetlands for polishing

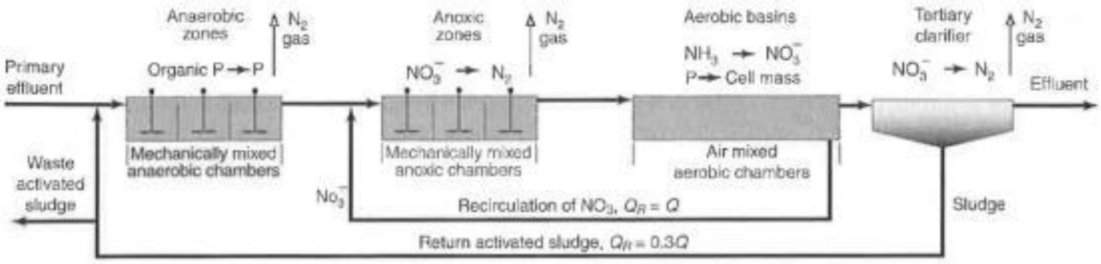
Constructed wetland polishing, also referred to as maturation or polishing ponds, are used as third-stage natural polishing of effluent from activated sludge or trickling-filter secondary treatment. The wetlands can be constructed as described in more detail in S8: Constructed wetland: Subsurface and free-water-surface flow. A stabilisation of the treated water derives from retention in the pool and where suspended solids, BOD, faecal microorganisms and ammonia are reduced by retention and surface aeration (Hammer & Hammer 2012). Detention times range from 10 to 15 days. The treated effluent can be reused for nature conservation or agriculture (Ravazini et al., 2006).

Figure 24 Polishing constructed wetland Everstekoog, Texel, The Netherlands (IEES, 2013)

Advantages: Total nitrate removal is achievable when low flows are applied **(Ravazini et al., 2006)**;
Disadvantages: Precipitation events may affect pollutant removal efficiency;
Pre-treatment: Secondary treatment from activated sludge or trickling-filters (Hammer & Hammer 2012)

Enhanced biological phosphorus removal (EBPR)

For biological nitrogen removal, nitrification-denitrification processes are controlled by exposing the wastewater first to anoxic (total oxygen depletion) conditions followed by an aerobic zone. For phosphorous removal, the anoxic zone can be preceded by an anaerobic zone, which promotes the biological release of organic phosphorous and stimulates the phosphorus uptake of bacteria in the aerobic zone (Hammer and Hammer 2012, page 405). The anaerobic and anoxic zones are mixed by propellers while the aerobic zone is aerated zone is supplied with air by blowers.



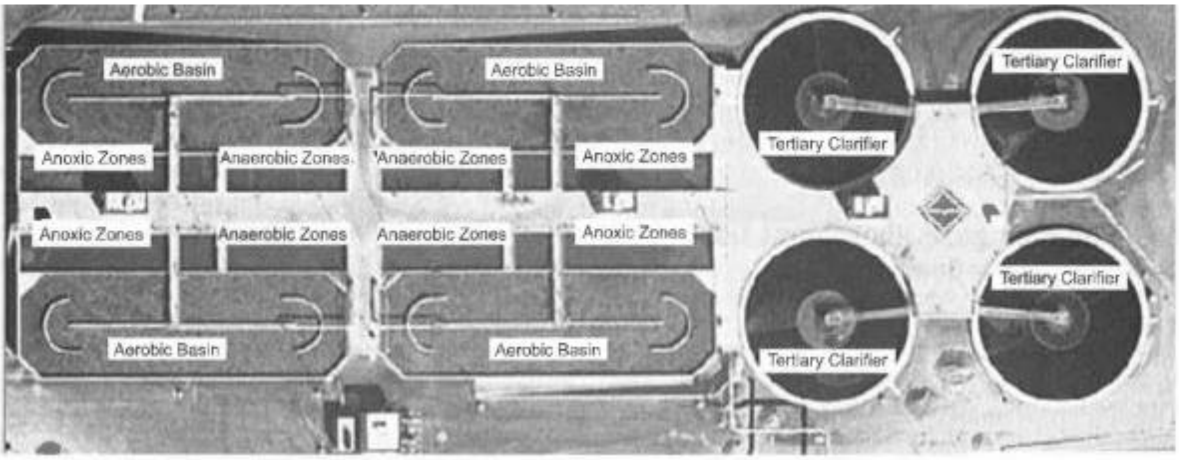


Figure 25 A three-stage biological phosphorus and nitrogen removal process. Schematic diagram (upper panel) and basins under operation (lower panel), source: Hammer and Hammer (2012)

P-Precipitation

Chemical precipitation refers to the induced settling of dissolved or suspended contaminants during wastewater treatment through the use of a coagulant. The settled substances can then be removed from the remaining wastewater e.g. by filtration or centrifugation. For phosphorus precipitation, most commonly ferric chloride (FeCl3), alum (Al2(SO4)3) or lime (CaO) are used. When ferric chloride or alum is used, the precipitate is a metal phosphate and the reaction is pH-dependent. The usage of lime requires the addition of sufficient quantities until the wastewater has a pH of at least ten, under which conditions Ca2+ will react with phosphorus to an insoluble precipitate. The amount of coagulant required cannot be calculated on the basis of P-concentration alone, but on a case-by-case analysis in the laboratory (jar tests) due to competing reactions with other compounds (EPA, 2000c).

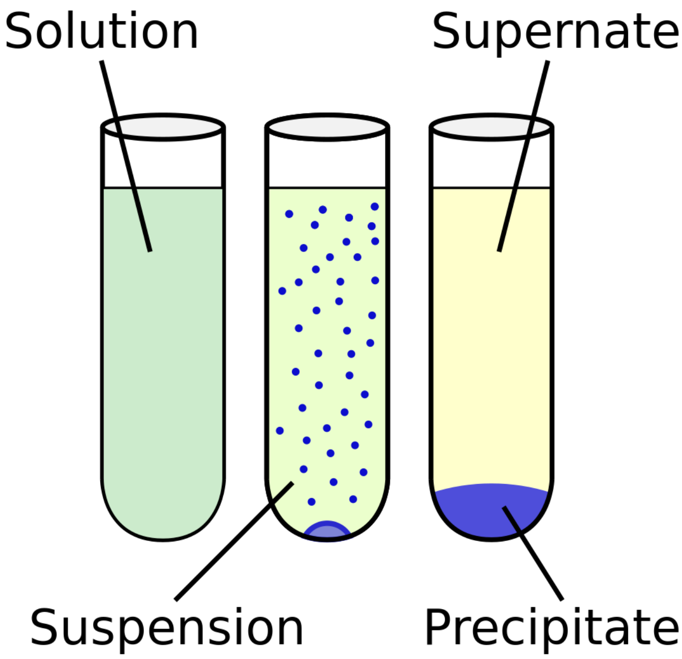


Figure 26 P-Precipitation (www.boundless.com)

Advantages: Readily available chemicals and equipment; lime is inexpensive; low maintenance
Disadvantages: Dosage must be determined case-by-case; corrosive chemicals; waste sludge amount may increase by up to 50 %, especially with lime (US-EPA, 2000b); large amount of chemicals

Pre-treatment: None necessary. Can be applied at different stages during the wastewater treatment process.

Nitrification-Denitrification

Nitrification of wastewater may be necessary if the effluent pollutes receiving water bodies, e.g. for environmental water reuse. The nitrification process converts nitrogen to the nitrate form and denitrification removes it from the wastewater by converting it into gaseous nitrogen. For nitrification, usually the most reliable process is suspended-growth aeration after activated sludge treatment, which provides a good growth environment with low BOD and high ammonia values for nitrifying bacteria. After nitrification, a final settling stage removes part of the population of nitrifiers which can be returned to the aeration tank. While nitrification reduces ammonia and its toxic effects in the effluent, it thus increases nitrate content. By a subsequent denitrification stage, nitrate in converted into gaseous nitrate and removed from the effluent. This is commonly achieved by a biological denitrification tank after nitrification, in which a carbon source (usually methanol) is needed for biological synthesis. Also after the denitrification tank a final settling and return of sludge is required.

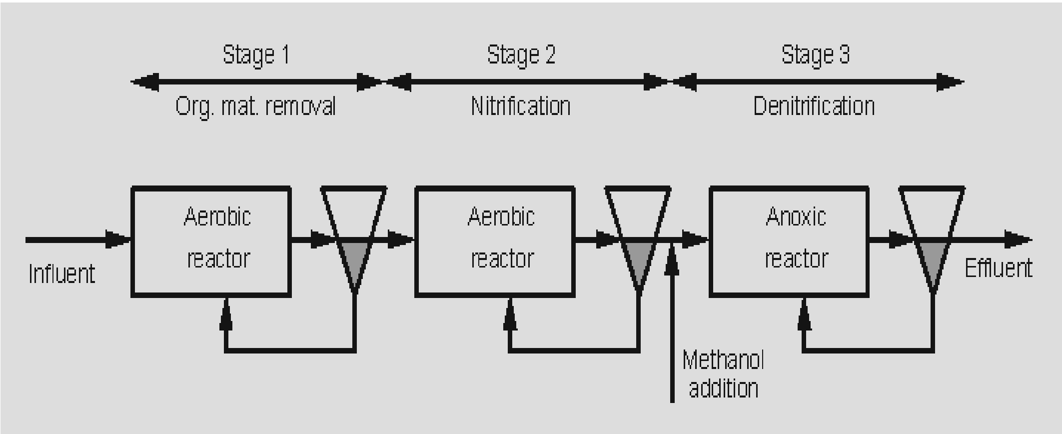


Figure 27 Denitrification process (http://en.wikipedia.org/wiki/File:Denitrification_with_external_carbon_source.gif)

Filtration over fine porous media and dual media filtration

Secondary effluent is applied to the fine porous media filter (=granular media filter), which commonly consists of a coal-sand or mixed (anthracite coal, garnet and sand) dual media (Hammer & Hammer 2012). The residues removed from the water are cleaned from the filter media by backwashing which requires a rotating agitator or air scrubbing for improved efficiency. The backwash water is stored in an equalizing tank and returned to the influent at a constant rate. Commonly, two to four filter cells are necessary to provide flexibility for varying flow rates (Hammer & Hammer 2012).

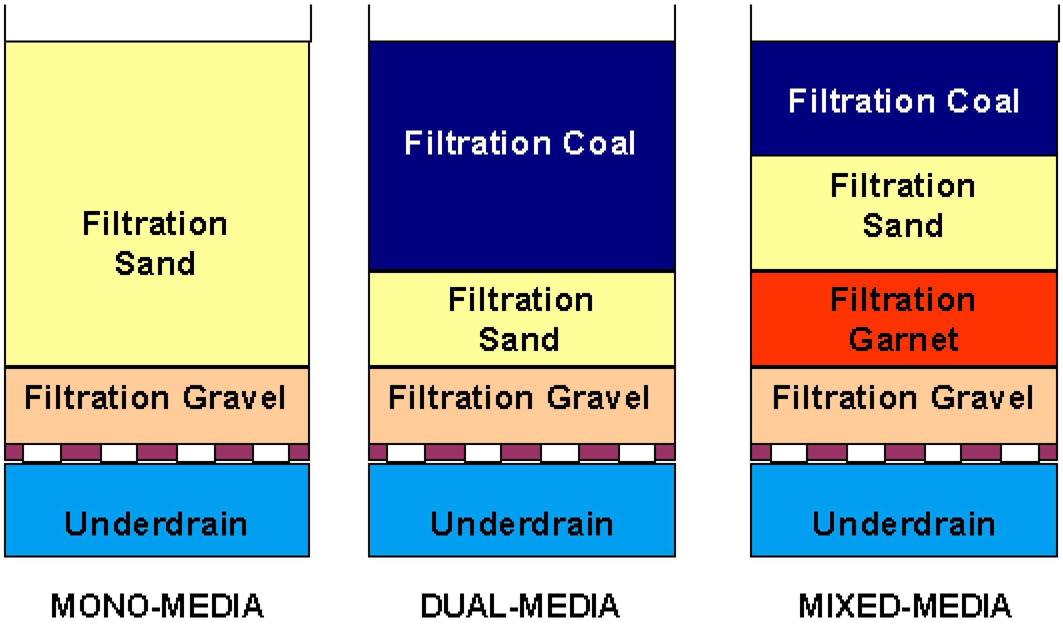


Figure 28 Dual media filter (source: blueplanet, 2013)

Microfiltration, ultrafiltration and nanofiltration

Microfiltration, ultrafiltration and nanofiltration are membrane filtration processes with removal capabilities differing in particle size (**Figure 9**). Micro- and ultrafiltration are based on physical straining to remove colloidal and particulate contaminants. Nanofiltration and reverse osmosis (T6) use semipermeable membranes to separate dissolved salts, organic molecules and metal ions (Hammer & Hammer, 2012). Nanofiltration membranes are able to remove turbidity, microorganisms and hardness and, to some extent, dissolved salts. The nanofiltration membrane is pressure-driven and its removal properties lie between ultrafiltration and reverse osmosis (US-EPA, 2004a). "Similar to other membrane processes, a major problem in NF membrane applications is fouling. Several studies have investigated the mechanisms of fouling in NF membranes and suggested methods to minimize and control the fouling of NF membranes" (Hilal, Darwish, Mohammad, & Arabi, 2004). The membrane type (pore size) is chosen based on the particle sizes of contaminants.

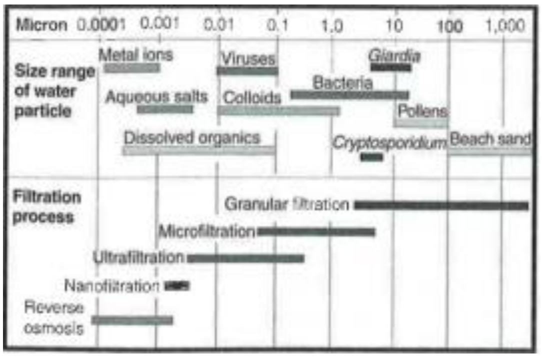


Figure 29 Typical sizes of contaminants commonly found in wastewater and removal efficiencies of membranes and reverse osmosis (source: Hammer and Hammer 2012)

Table 13 Design criteria and applications for filtration processes and reverse osmosis (adapted from Hammer and Hammer 2012

Process	Operating	Recovery	Flux	Applications

	pressure	(percent)	(m day^{-1})	
T3: Microfiltration	**0.3 to 2.8 bar**	**95-98**	**12**	**Suspended solids and bacteria removal**
T4: Ultrafiltration	**1 to 4 bar**	**80-95**	**0.5-10**	**Virus removal and pre-treatment for reverse osmosis**
T5: Nanofiltration	**5 to 14 bar**	**70-90**	**0.3-1**	**Special applications**
T6: Reverse osmosis	**10 to 41 bar**	**70-85**	**0.4 to 0.8**	**Demineralization, total dissolved solids removal**

Microfiltration

Microfiltration by membranes and hollow fibres has become an interesting water disinfection alternative and cost have decreased during the last years (Davide Bixio et al., 2006).
Advantages: No hazardous by-products; variable cost comparable to UV disinfection of effluent filtered through conventional sand filtration (Davide Bixio et al., 2006); complete removal of bacteria is possible
Disadvantages: Fixed cost higher than UV disinfection;

Ultrafiltration

Disadvantages: Higher energy demand than microfiltration

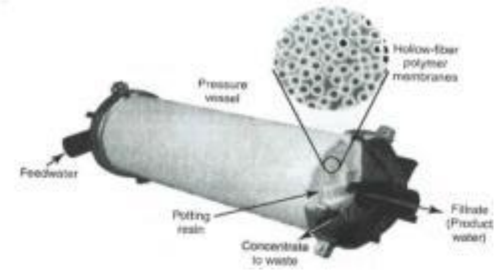


Figure 30 Example of a ultrafiltration hollow-fibre module (source: Hammer and Hammer 2012)

Nanofiltration

Advantages: Lower operation pressure than reverse osmosis; high water flux; high retention of multivalent anion salts and an organic molecular above 300 (Hilal et al., 2004);
Disadvantages: Fouling; low recovery (82.5 %, Joksimovic 2005)

Reverse osmosis

Reverse osmosis is the forced passage of water through a semipermeable membrane against the osmotic pressure gradient. In order to force the passage, an external pressure should be applied to the wastewater. This separates dissolved solids from the water forced through the membrane. Typical pressure ranges used in reverse osmosis applications are 350 to 800 psi.

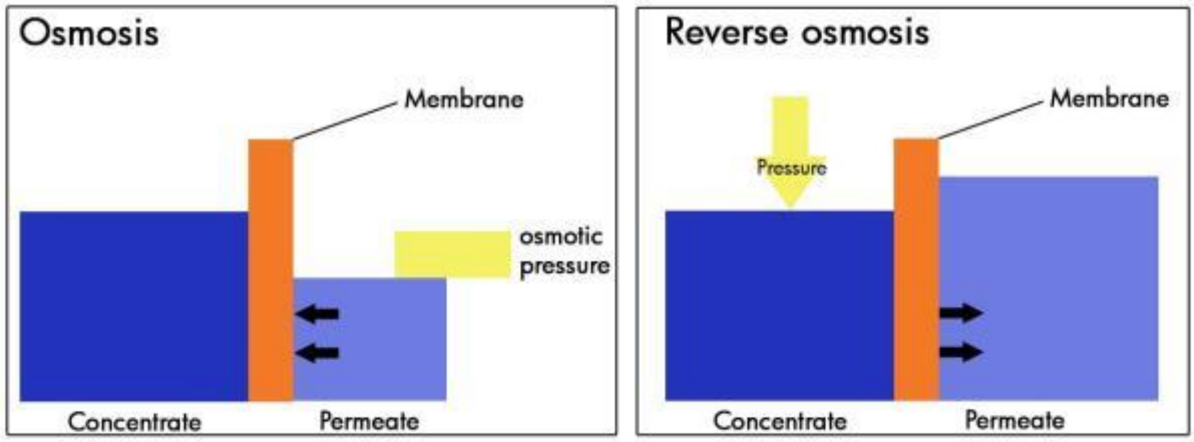


Figure 31 Principle of reverse osmosis (Hydrotec, 2013)

Disadvantages: High concentrates production (reject water) are a critical economic and environmental problem (Hammer & Hammer 2012)
Influent: Especially the removal of solids is an essential pre-treatment requirement for reverse osmosis. A sufficient level of pre-treatment can be either achieved through a series of precipitation, sedimentation, recarbonation, granular-media filtration and carbon filtration or microfiltration/ultrafiltration with chemical additions (Hammer & Hammer, 2012).

Granular activated carbon (GAC) and powdered activated carbon (PAC)

Granular activated carbon (GAC) is an effective treatment process removing biodegradable and refractory organic compounds. Carbon adsorption is usually considered the most effective way to reduce the level of taste and odour in water treatment (Hammer & Hammer, 2012). GAC works by adsorption of organic compounds onto the carbon. Further substances which can be removed from reclaimed water by GAC include metal ions such as cadmium, hexavalent chromium, silver and selenium. From acidic water, also some uncharged chemicals including arsenic and antimony can be removed (US-EPA, 2004a). Activated carbon is produced from carbonaceous materials (charcoal, coconut shells, etc.) by a controlled combustion (Hammer & Hammer, 2012). Powdered activated carbon (PAC), as granular activated carbon (GAC), is also produced from carbonaceous materials (charcoal, nut shells, etc.) by a controlled combustion. In its fine power form PAC it can be applied at any location in the treatment process prior to filtration. PAC can adsorb organic compounds related to taste and odour of water, but is less effective for absorbing SOCs (Synthetic Organic Chemicals) than GAC (Hammer & Hammer, 2012).

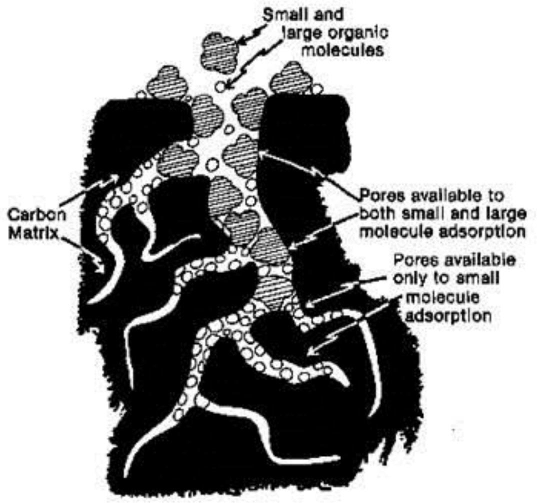


Figure 32 Activated carbon matrix (can be used in different forms), source: (Wateen Solutions, 2013)

Advantages: Reliability; proven adsorption efficiency for dissolved organics, especially from industrial sources (EPA, 2000); low space requirements; ease of integration into existing systems
Disadvantages: Wet GAC is highly corrosive; disposal if GAC is not regenerated; regeneration process is most efficient if run 24 hours, thus requiring around the clock surveillance (EPA, 2000); air emissions from regeneration furnace usually require afterburners and scrubbers
Pre-treatment: Secondary treated wastewater with low suspended solid contents.

Ion exchange

In the ion exchange process, anions or cations from the wastewater solution are exchanged with different but equivalently charged ions from a resin bed. Thus, the salts in the solution must be ionized for the process to occur. Exchange beds are usually resins of 0.3 to 1.2 mm in diameter. Ion exchange is used to remove specific ions such as nitrate, fluoride, arsenic, calcium, magnesium and other substances. Regeneration of the brine is usually conducted by backwashing with product water followed by flushing with a brine for regeneration to replace the exchanged ions from the resin (Hammer & Hammer, 2012).

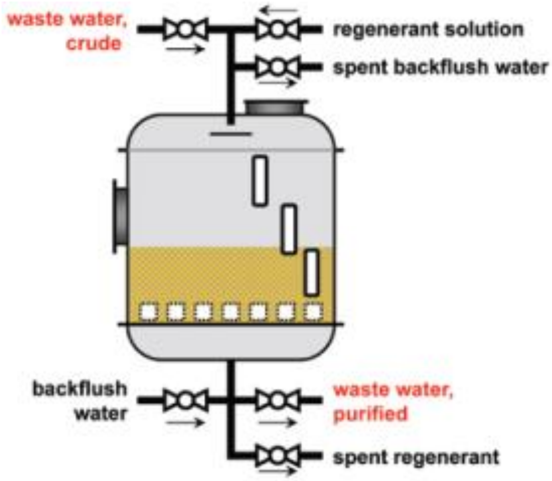


Figure 33 Typical ion exchange column used in wastewater treatment (source: Neumann & Fatula, 2009)

Disadvantages: Brine wastewater disposal;

Advanced oxidation – UV/O_3 and UV/H_2O_2

Photolysis by ultraviolet (UV) radiation (process **D5**) is widely used for disinfection. Ozone (O_3, process **D1**) is used for water disinfection, taste and odour control and removal of colours in water treatment (Matilainen & Sillanpää, 2010). To overcome the disadvantages of single disinfectants, there have been relatively recent research efforts to combine strong oxidants for better disinfection properties and reduction of emerging pollutants such as pharmaceutical compounds and their derivates, anti-corrosion agents, hormone active substances etc. Two examples considered here are the combination of UV with ozone for improved microorganism removal and UV with peroxone for effective disinfection and DOM (Dissolved Organic Matter) removal. Furthermore, advanced oxidation may be used to treat wastewater, drinking water, contaminated soils or sludges for several types of contaminants including organic pollutants, toxicity biodegradability improvement, odour and colour removal and destruction of resin in radioactive contaminated sludge (Davide Bixio et al., 2006). The main characteristic which makes AOPs very efficient processes is the formation of free hydroxyl radicals ($OH\cdot$), which is one of the most powerful oxidising species known.

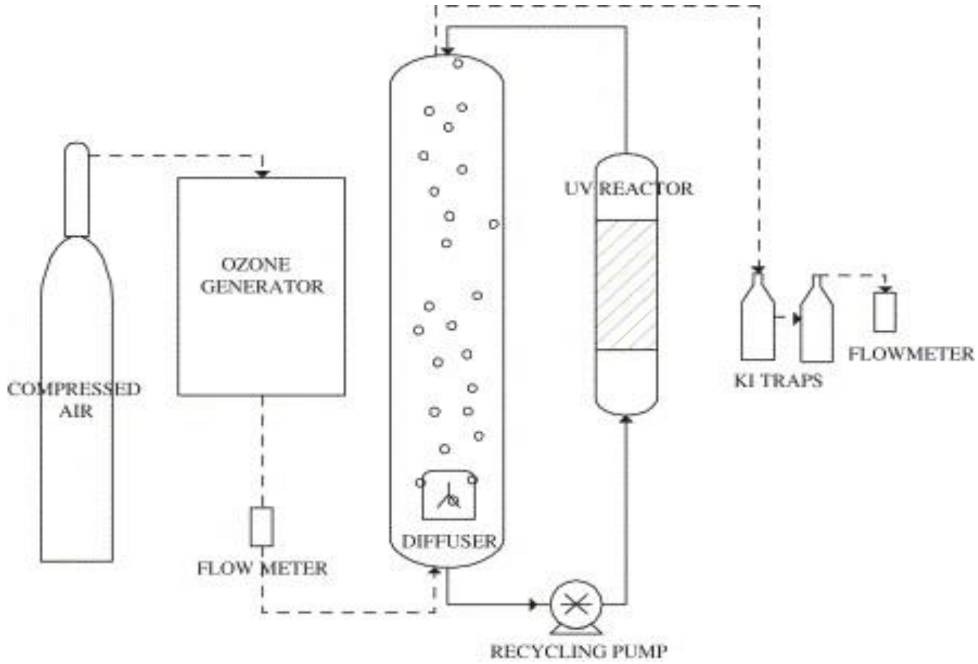


Figure 34 Oxidation batch (Removal of disinfection by-product precursors with ozone-UV advanced oxidation process A. Chin et. Al, 2005)

Advantages: High quality purified water; (partial) micropollutant removal and degradation
Disadvantages: Formation of by-products possible; expensive

Soil-aquifer treatment (SAT)

Reclaimed water can be used to preserve groundwater levels, protect coastal aquifers against saltwater intrusion and to store water for future use by groundwater recharge. Infiltration into the aquifer is by spreading basins where water percolates vertically through the soil or river bank infiltration. The passage through soil further contributes to purification of the effluent. Soil permeability can be negatively affected by clogging with operation time (Wintgens et al., 2006).

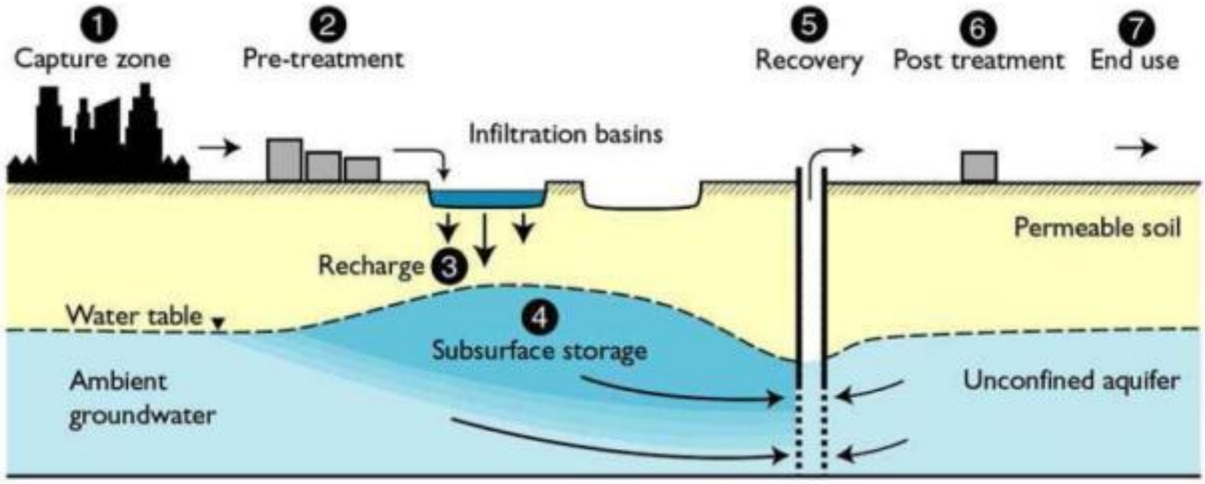


Figure 34 SAT system for pre-treated wastewater, infiltrating through recharge basins into permeable soil (unsaturated zone) and recharging the groundwater aquifer (Miotli, Barry, Dillon, & Breton, 2010).

Maturation pond

Maturation ponds are valuable and simple options to polish secondary effluent. They are used primarily for high-level pathogen removal and to a minor extent, for additional removal of nutrients (Davide Bixio et al., 2006). If the systems are well designed, effluent quality can comply with WHO guidelines for safe use of wastewater, excreta and greywater. Maturation ponds receive inflow year around and discharge by overflow and are usually preceded by a series of anaerobic and facultative ponds (mainly for BOD removal). The hydraulic retention time and design criteria (size, number of ponds and type of flow) define the effluent water quality.

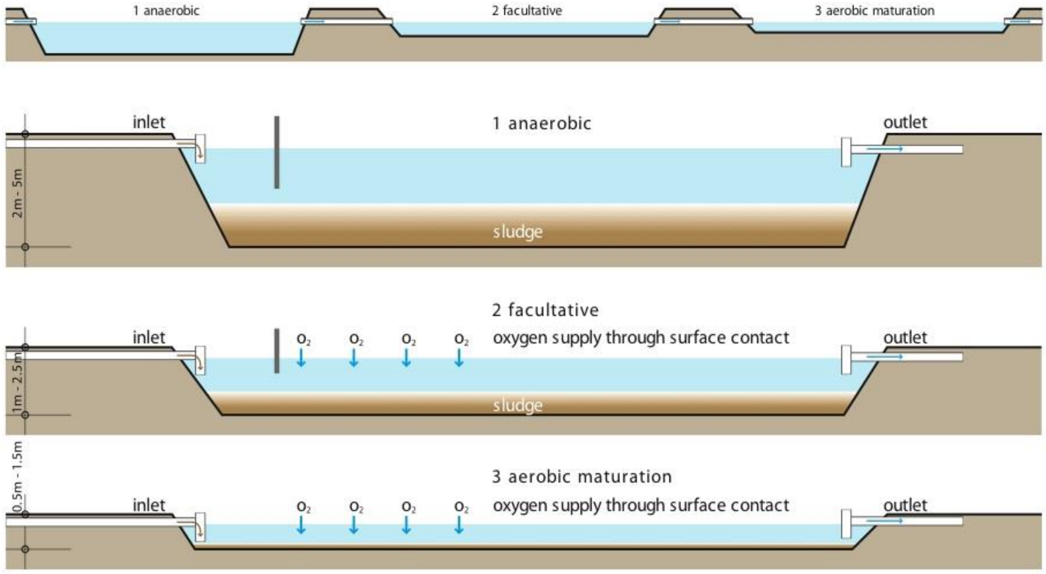


Figure 15 Maturation Pond (www.sswm.info Tilley et al. 2008)

Flocculation

Flocculation is a chemical process by which suspended solids aggregate to larger clumps ('flocs') (US-EPA, 2004b). These flocs are then easier to remove by subsequent sedimentation and filtration processes.

Ballasted flocculation is also known as high rate clarification and is a physical-chemical treatment that improves settling properties of suspended solids by continuously recycled media and additives. The so formed microfloc particles should have a gravity greater than two. Clarification occurs about ten times faster than with conventional clarification due to decreased settling time. Microsand, a microcarrier or chemically enhanced sludge can be used as ballast material. In addition, a coagulant (e.g., ferric sulphate) and and anionic polymer have to be added. The unit has a compact size and is attractive for retrofit and high rate applications (US-EPA, 2002).

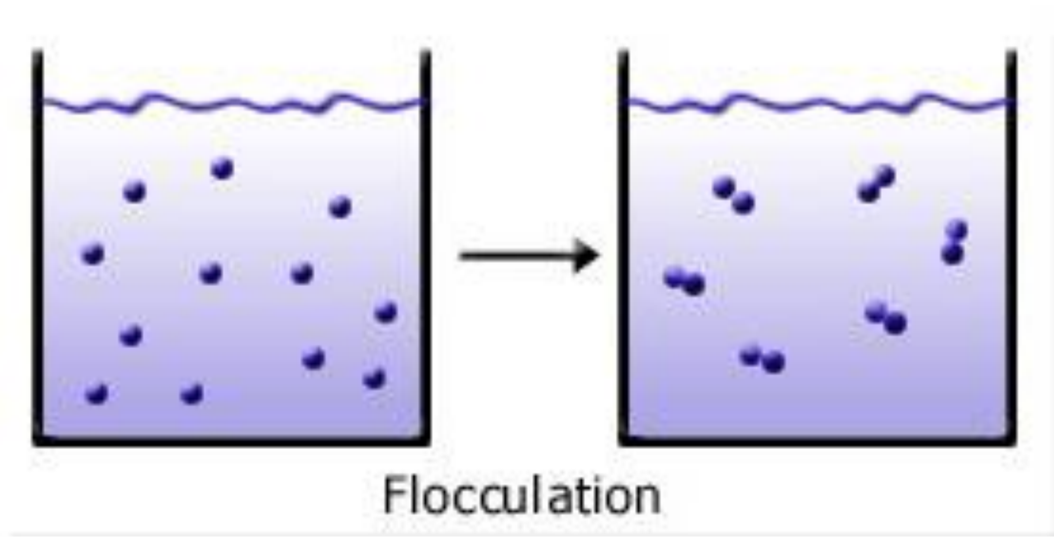


Figure 36 Flocculation (water.me.vccs.edu)

Advantages: Reduced surface area for clarifiers; adjustable to wider range of flows without reducing removal efficiencies
Disadvantages: Require operator judgement and more complex instrumentation than conventional systems; pumps may be affected by ballast material; lost ballast material must be occasionally replaced

Electrodialysis

Electro Dialysis (ED) is a membrane process, during which ions are transported through semi permeable membrane, under the influence of an electric potential. (Lenntech, 2013) This process is often used for desalination or to process industrial water and the technology is applied worldwide.

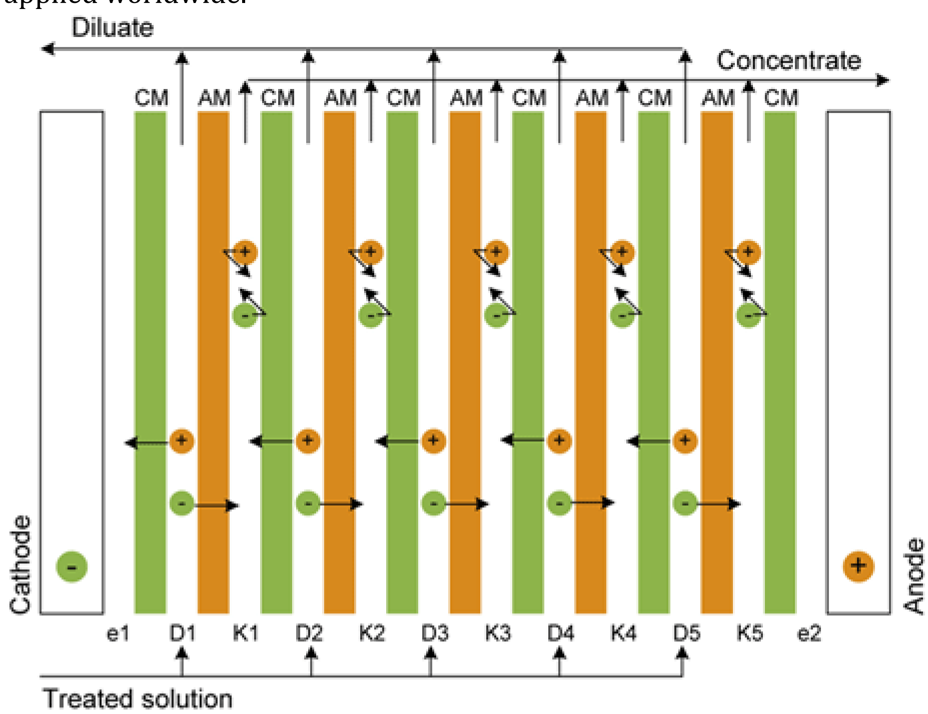


Figure 37 Electrodialysis principle (source: novasep, 2013)

Ozonation

Ozone is a very strong oxidant and virucide and used for water disinfection, taste and odour control and removal of colours in water treatment (Matilainen & Sillanpää, 2010). Ozone (O_3) is produced by splitting up Oxygen (O_2) molecules by an energy source into oxygen radicals (O·). These radicals collide with oxygen molecules and form the unstable ozone molecule. In most WWTPs and WR&R facilities, ozone is produced by a high voltage discharge across a dielectric gap containing oxygen gas (US-EPA, 1999a). Since ozone is not stable, it has to be produced onsite.

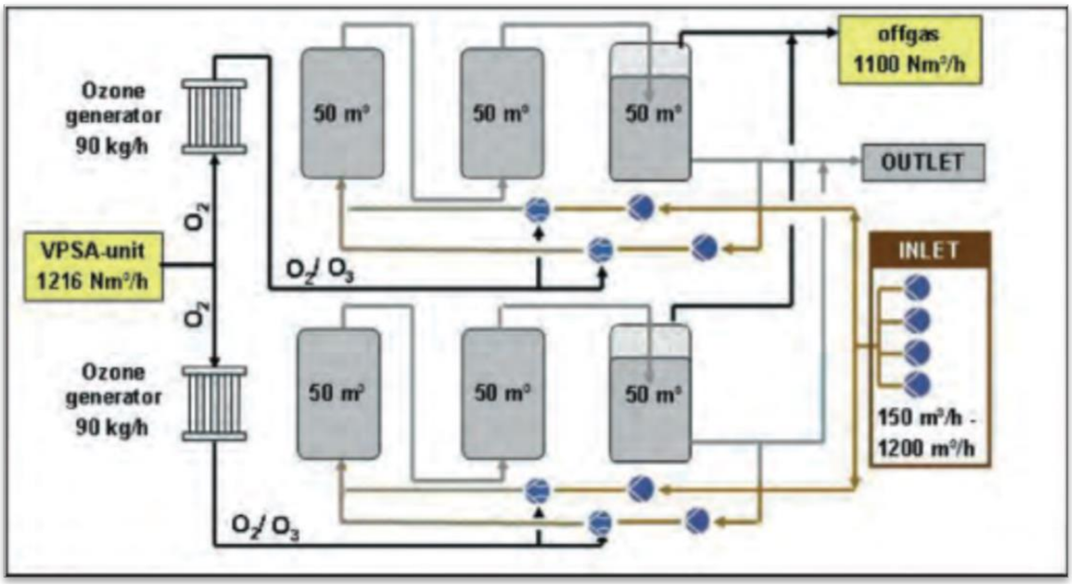


Figure 38 Ozonation (Bixio et. al. 2006)

Advantages: More effective than chlorine against viruses and bacteria (US-EPA, 1999a); short contact time and generally more rapid than chlorination; no potentially harmful by-products like trihalomethanes (THMs); excellent removal of taste and odours;
Disadvantages: Similar to chlorine, ozone may not kill cysts and some other large organisms so these should be eliminated by filtration or other procedures prior to treatment; ozone must be generated before use and the equipment and operating costs can be quite high; lack of active residuals may be a drawback in large distribution systems compared to chloride; off-gas from contactor must be destroyed to avoid risk for workers
Pre-treatment: Ozone disinfection is generally used at medium to large sized plants after at least secondary treatment (US-EPA, 1999a).

Chlorination

Chlorine is the most widely used chemical for disinfection. It is a strong oxidiser, highly corrosive and its vapour irritates the respiratory tract. Water treatment plants usually use liquid chlorine which together with water reacts to hypochlorous acid and in a second step to the hypochlorite ion. At a pH above 8, predominantly the hypochloride ion is present while a pH below 7 favours hypochlorous acid. The latter is more effectively disinfecting water by interacting with microbial cell structures. The required chlorine dosage depends on pH, interfering substances, temperature and contact time and is between 8 and 15 mg l^{-1} in well-designed units (Hammer & Hammer 2012). While chlorine has a long standing history of as an effective disinfectant against a broad range of pathogens, it has drawbacks including health hazards which need to be effectively monitored (chloric gas) and the possibility of the formation of hazardous by-products such as THMs (trihalomethanes, EPA, 2012). In wastewater treatment plants chlorine can be added at the raw water intake or prior to sedimentation for pre-chlorination (control of biological growth, disinfection, iron and manganese oxidation, odour control), ahead of filters for intermediate chlorination (control of biological growth, algae control, odour control), at the filter clearwell for postchlorination and before discharge into a distribution system (rechlorination) (EPA, 1999). Chlorine is usually produced off-site and transported and stored in pressurized steel cylinders.

D2: **Chlorine gas**. The most commonly applied form.

D3: **Chlorine dioxide**. Application of ClO_2., which is produced at the wastewater treatment plant by mixing sodium chlorite ($NaClO_2$) and chlorine. Major disadvantages are that sodium chlorite is expensive and that there is the potential of toxic product formation (chlorate and chlorite residuals).

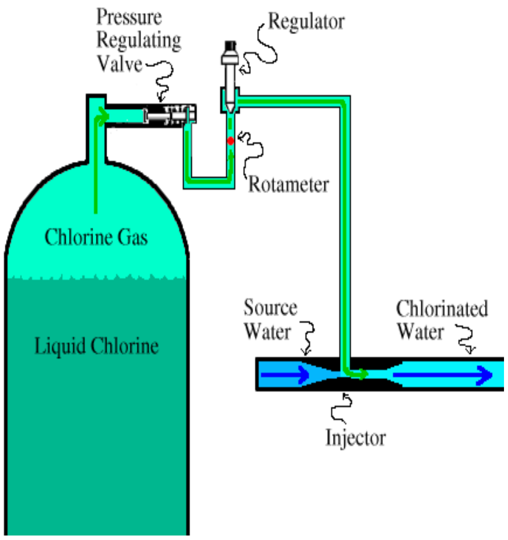


Figure 39 Chlorine Gas
(www.camix.com.vn)

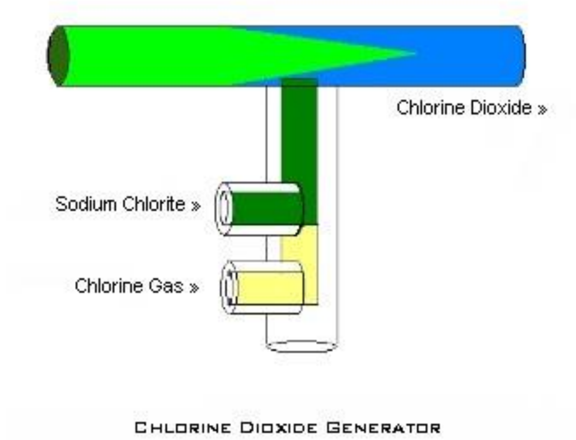


Figure 40 Chlorine Dioxide
(www.cip.ukcentre.com)

Advantages: Highly effective disinfection; established method; chlorine concentration remaining in the effluent after disinfection its action; besides pathogens, chlorine can also oxidize certain chemical pollutions; elimination of some odorous components
Disadvantages: Highly corrosive; toxic to aquatic life; hazardous by-products can be formed; some parasites are resistant at different life stages to chlorine, including oocysts of *Cryptosporidium parvum*, cysts of *Giardia lamblia* and eggs of parasitic worms (EPA, 2012)
Pre-treatment: Nitrite content should be minimized to avoid the formation of THMs; TSS can shield some pathogens from chloride action and should be minimized before chloride treatment

Ultraviolet disinfection

Process description: UV-photolysis is a widely used process for water disinfection purposes. UV radiation has wavelengths between 200 and 300 nm, penetrates water and damages DNA of organisms, thus inhibiting their reproduction. Furthermore, UV radiation damages viruses and bacteria in their spore and cyst forms. UV transmittance of wastewater depends on the concentration of suspended solids, colour, lamp fouling and others. Shielding of microorganisms from UV by clumping or solids is possible.

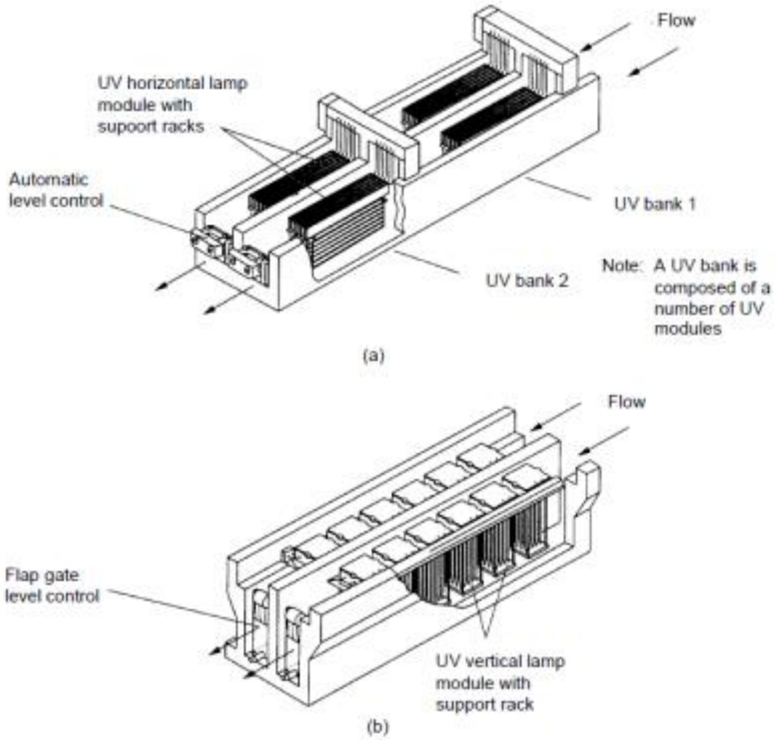


Figure 41 Two typical UV disinfection systems

Advantages: Effective inactivation of many viruses, spores and cysts; no need to store and handle hazardous substances compared to chemical disinfection; easy to operate; short contact time compared to chemical disinfection (ca. 20 to 30 seconds with low-pressure lamps, EPA 1999); not harmful to the environment and personnel
Disadvantages: High operating cost; anything which blocks UV light from reaching the water will result in a lack of treatment and water must be free of turbidity; some organisms can repair the destructive effect of UV radiation through photo reactivation or dark repair (US-EPA, 1999b)
Influent: Very low turbidity required

Appendix III: Unit Process Data

A3.1 Table for the first 6 parameters.

The shading refers to references mentioned in Table 14. This table presents the removal efficiency of every unit process for every parameters in [%]. For each parameter, 3 removal efficiencies are indicated: min, average and max, referring to minimal, average or maximal performance of unit processes.

Name	Turb			TSS			BOD			COD			TN			TP		
NONE	min	% av.	max	min	% av.	max	min	% av.	max	min	% av.	max	min	% av.	max	min	% av.	max
P1 - Bar screen	0.00	0.00	0.00	0.00	2.00	5.00	0.00	2.00	2.50	0.00	1.30	1.50	0.00	0.00	0.00	0.00	0.00	0.00
P2 - Coarse screen	0.00	0.00	0.00	0.00	5.00	15.00	2.00	4.00	6.00	1.00	2.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
P3 - Grit Chamber	1.00	2.00	3.00	1.00	2.00	3.00	0.00	2.00	5.00	0.00	2.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00
P4 - Equalization Basin	0.00	0.00	0.00	0.00	0.00	0.00	4.00	12.00	15.00	4.00	12.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00
P5 - Sedimentation without coagulant	0.00	0.00	0.00	30.00	50.00	60.00	20.00	25.00	30.00	20.00	25.00	30.00	5.00	7.00	9.00	5.00	7.00	9.00
P6 - Sedimentation with coagulant	50.00	70.00	80.00	60.00	70.00	80.00	40.00	50.00	60.00	40.00	50.00	60.00	0.00	15.00	30.00	40.00	50.00	60.00
P7 - Anaerobic stabilization ponds	15.00	70.00	75.00	30.00	45.00	60.00	40.00	65.00	90.00	30.00	58.00	85.00	25.00	48.00	70.00	5.00	7.00	10.00
S1 - Activated sludge	80.00	90.00	99.00	50.00	70.00	99.00	50.00	70.00	99.00	60.00	80.00	94.00	10.00	30.00	96.00	10.00	23.00	45.00

S1-A - Low Loaded Activated Sludge w/o de-N + Sec Sedim.	89.00	98.00	99.00	90.00	97.00	98.00	95.00	97.00	98.00	87.00	90.00	94.00	10.00	30.00	50.00	10.00	22.50	45.00
S1-B - Low Loaded Activated Sludge w de-N + sec. Sedim.	93.00	98.00	99.00	90.00	97.00	99.00	93.00	98.00	99.00	87.00	90.00	94.00	68.00	87.00	96.00	10.00	27.50	45.00
S1-C - High Loaded Activated Sludge + Sec. Sedim.	89.00	97.00	99.00	86.00	96.00	98.00	89.00	95.00	99.00	85.00	90.00	94.00	10.00	20.00	30.00	10.00	17.50	25.00
S1-D - Extended aeration	90.00	99.00	99.00	82.00	88.00	79.00	85.00	90.00	95.00	89.00	90.00	95.00	50.00	72.00	90.00	90.00	99.90	99.90
S2 - Trickling filter with secondary sedimentation	20.00	30.00	45.00	50.00	70.00	85.00	50.00	70.00	85.00	65.00	80.00	90.00	20.00	30.00	40.00	20.00	30.00	40.00
S3 - Rotating biological contactor (RBC)	50.00	70.00	85.00	35.00	60.00	70.00	35.00	60.00	70.00	65.00	70.00	85.00	20.00	30.00	35.00	20.00	30.00	40.00
S4 - Stabilization ponds: Aerobic	50.00	60.00	75.00	30.00	45.00	60.00	40.00	60.00	80.00	35.00	40.00	60.00	25.00	45.00	60.00	20.00	40.00	50.00
S5 - Stabilization ponds: Facultative	40.00	50.00	60.00	50.00	70.00	85.00	50.00	70.00	85.00	60.00	80.00	90.00	20.00	40.00	60.00	25.00	50.00	70.00
S6 - Membrane bioreactor (MBR)	90.00	92.00	95.00	90.00	92.00	100.00	90.00	92.00	95.00	75.00	80.00	85.00	30.00	40.00	50.00	60.00	70.00	80.00

T1 - Constructed wetland	10.00	15.00	40.00	60.00	75.00	85.00	25.00	35.00	50.00	10.00	15.00	20.00	50.00	60.00	80.00	50.00	60.00	80.00
T2 - Enhanced biological phosphorus removal (EBPR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	95.00	98.00
T3 -P-Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	70.00	95.00	98.00
T4 - Denitrification	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	95.00	98.00	0.00	0.00	0.00
T5 - Dual media filter	80.00	90.00	95.00	80.00	90.00	95.00	65.00	75.00	80.00	60.00	70.00	75.00	5.00	10.00	12.00	6.00	10.00	12.00
T6 - Microfiltration	85.00	90.00	95.00	80.00	90.00	95.00	65.00	75.00	80.00	60.00	70.00	75.00	5.00	10.00	12.00	6.00	10.00	12.00
T7 - Ultrafiltration	80.00	90.00	95.00	80.00	90.00	95.00	65.00	75.00	80.00	60.00	70.00	75.00	5.00	10.00	12.00	6.00	10.00	12.00
T8 - Nanofiltration	30.00	50.00	70.00	99.00	99.95	99.90	80.00	90.00	95.00	80.00	90.00	95.00	40.00	40.00	40.00	90.00	95.00	99.00
T9 - Reverse osmosis	30.00	50.00	70.00	80.00	90.00	95.00	20.00	35.00	50.00	60.00	70.00	75.00	40.00	40.00	40.00	80.00	90.00	95.00
T10 - Activated Carbon	20.00	40.00	60.00	40.00	45.00	50.00	40.00	45.00	50.00	20.00	30.00	40.00	0.00	0.00	0.00	8.00	15.00	25.00
T11 - Ion exchange	10.00	20.00	30.00	40.00	45.00	50.00	10.00	20.00	30.00	0.00	0.00	0.00	60.00	70.00	80.00	70.00	80.00	90.00
T12 - Advanced oxidation process		80.00	90.00	0.00	0.00	0.00	70.00	80.00	90.00	70.00	80.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00
T13 - Soil-aquifer treatment (SAT)	85.00	85.00	85.00	80.00	90.00	95.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	80.00	90.00	95.00

T14 - Maturation pond	30.00	45.00	60.00	15.00	25.00	40.00	8.00	13.00	20.00	10.00	20.00	30.00	30.00	40.00	45.00	20.00	30.00	40.00
T15 - Flocculation	20.00	30.00	50.00	40.00	60.00	80.00	20.00	30.00	40.00	15.00	35.00	50.00	5.00	8.00	13.00	10.00	15.00	30.00
T16 - Electrodialysis	70.00	80.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.00	50.00	60.00	40.00	50.00	60.00
D1 - Ozonation	0.00	0.00	0.00	0.00	0.00	0.00	10.00	15.00	20.00	10.00	15.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00
D2 - Chlorine gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D3 - Chlorine dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D4 - Ultraviolet disinfection	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

A3.2 Table for the last 6 parameters.

The shading refers to references mentioned in Table 14. This table presents the removal efficiency of every unit process for every parameters in [%]. For each parameter, 3 removal efficiencies are indicated: min, average and max, referring to minimal, average or maximal performance of unit processes.

Name	TP			FC			TC			Conductivity			Nitrate			Virus			Virus (log removed)		
NONE	min	% av.	max	min	% av.	max	min	% av.	max	min	% av.	max	min	% av.	max	min	% av.	max	min	av	max
P1 - Bar screen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P2 - Coarse screen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P3 - Grit Chamber	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P4 - Equalization Basin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P5 - Sedimentation without coagulant	5.00	7.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	68.38	90.00	0.00	0.50	1.00
P6 - Sedimentation with coagulant	40.00	50.00	60.00	10.00	15.00	30.00	5.00	10.00	20.00	-10.00	-5.00	0.00	0.00	0.00	0.00	0.00	68.38	90.00	0.00	0.50	1.00
P7 - Anaerobic stabilization ponds	5.00	7.00	10.00	30.00	50.00	60.00	20.00	35.00	45.00	0.00	0.00	0.00	90.00	95.00	100.00	90.00	99.68	99.99	1.00	2.50	4.00
S1 - Activated sludge	10.00	23.00	45.00	50.00	90.00	99.90	90.00	95.00	99.90	0.00	0.00	0.00	-20.00	0.00	20.00	0.00	90.00	99.00	0.00	1.00	2.00
S1-A - Low Loaded Activated Sludge w/o de-N + Sec Sedim.	10.00	22.50	45.00	99.50	99.80	99.92	99.90	99.95	99.99	0.00	0.00	0.00	-20.00	0.00	20.00	0.00	90.00	90.00	0.00	1.00	1.00

S1-B - Low Loaded Activated Sludge w de-N + sec. Sedim.	10.00	27.50	45.00	99.50	99.80	99.92	99.90	99.95	99.99	0.00	0.00	0.00	-20.00	0.00	20.00	0.00	90.00	90.00	0.00	1.00	1.00
S1-C - High Loaded Activated Sludge + Sec. Sedim.	10.00	17.50	25.00	50.00	90.00	98.00	90.00	95.00	99.90	0.00	0.00	0.00	-20.00	0.00	20.00	0.00	90.00	68.38	0.00	1.00	0.50
S1-D - Extended aeration	90.00	99.90	99.90	90.00	94.95	99.90	90.00	94.95	99.90	0.00	0.00	0.00	-20.00	0.00	20.00	0.00	90.00	99.00	0.00	1.00	2.00
S2 - Trickling filter with secondary sedimentation	20.00	30.00	40.00	60.00	80.00	90.00	50.00	60.00	75.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00	99.00	0.00	1.00	2.00
S3 - Rotating biological contactor (RBC)	20.00	30.00	40.00	60.00	80.00	90.00	50.00	60.00	75.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.77	68.38	0.00	0.25	0.50
S4 - Stabilization ponds: Aerobic	20.00	40.00	50.00	10.00	15.00	30.00	5.00	10.00	20.00	0.00	0.00	0.00	-10.00	-5.00	0.00	90.00	96.84	99.00	1.00	1.50	2.00
S5 - Stabilization ponds: Facultative	25.00	50.00	70.00	10.00	15.00	30.00	10.00	20.00	30.00	0.00	0.00	0.00	-10.00	-5.00	0.00	90.00	99.68	99.99	1.00	2.50	4.00
S6 - Membrane bioreactor (MBR)	60.00	70.00	80.00	80.00	85.00	90.00	70.00	75.00	80.00	0.00	0.00	0.00	0.00	50.00	90.00	99.68	99.99	100.00	2.50	4.25	6.00
T1 - Constructed wetland	50.00	60.00	80.00	0.00	50.00	99.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	90.00	90.00	96.84	99.00	1.00	1.50	2.00

T2 - Enhanced biological phosphorus removal (EBPR)	50.00	95.00	98.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3 -P- Precipitation	70.00	95.00	98.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4 - Denitrification	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	70.00	90.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
T5 - Dual media filter	6.00	10.00	12.00	80.00	85.00	90.00	80.00	85.00	90.00	0.00	0.00	0.00	5.00	10.00	12.00	90.00	99.00	99.90	1.00	2.00	3.00
T6 - Microfiltration	6.00	10.00	12.00	90.00	93.00	99.00	80.00	85.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00	99.00	0.00	1.00	2.00
T7 - Ultrafiltration	6.00	10.00	12.00	99.00	99.90	99.99	80.00	85.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	99.00	100.00	100.00	2.00	4.50	7.00
T8 - Nanofiltration	90.00	95.00	99.00	99.00	100.00	100.00	90.00	93.00	95.00	20.00	60.00	90.00	20.00	50.00	80.00	99.90	99.99	100.00	3.00	4.00	5.00
T9 - Reverse osmosis	80.00	90.00	95.00	90.00	95.00	98.00	90.00	93.00	95.00	80.00	90.00	99.00	65.00	75.00	80.00	99.99	100.00	100.00	4.00	5.50	7.00
T10 - Activated Carbon	8.00	15.00	25.00	15.00	30.00	40.00	10.00	20.00	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.77	68.38	0.00	0.25	0.50
T11 - Ion exchange	70.00	80.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00							0.00	0.00	0.00	0.00	0.00	0.00
T12 - Advanced oxidation process	0.00	0.00	0.00	90.00	92.50	95.00	55.00	65.00	75.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00	96.84	99.00	1.00	1.50	2.00
T13 - Soil-aquifer treatment (SAT)	80.00	90.00	95.00	70.00	90.00	100.00	65.00	70.00	75.00	0.00	0.00	0.00	80.00	90.00	100.00	29.21	91.59	99.00	0.15	1.08	2.00
T14 - Maturation pond	20.00	30.00	40.00	30.00	50.00	70.00	20.00	35.00	50.00	0.00	0.00	0.00	-20.00	-10.00	0.00	99.90	99.97	99.99	3.00	3.50	4.00

T15 - Flocculation	10.00	15.00	30.00	10.00	20.00	40.00	5.00	15.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00	99.00	99.90	1.00	2.00	3.00
T16 - Electrodialysis	40.00	50.00	60.00	0.00	0.00	0.00	0.00	0.00	0.00	60.00	75.00	90.00	20.00	40.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00
D1 - Ozonation	0.00	0.00	0.00	90.00	95.00	98.00	90.00	92.00	95.00	0.00	0.00	0.00	0.00	0.00	0.00	99.90	100.00	100.00	3.00	4.50	6.00
D2 - Chlorine gas	0.00	0.00	0.00	90.00	95.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	99.00	99.90	100.00	2.00	3.00	6.00
D3 - Chlorine dioxide	0.00	0.00	0.00	90.00	95.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	99.00	99.90	100.00	2.00	3.00	6.00
D4 - Ultraviolet disinfection	0.00	0.00	0.00	90.00	95.00	100.00	55.00	65.00	80.00	0.00	0.00	0.00	0.00	0.00	0.00	99.00	99.90	100.00	2.00	3.00	6.00

A3.3 Table for other information and evaluation criteria.

These qualitative evaluation criteria are reported in (Adewumi, 2011a). In addition, several expert workshops have been conducted to fill the missing information and also by using additional references. Recovery is defined as the quantity of water effluent from a given unit process divided by the influent quantity and is required to calculate the end flow of the treatment trains. It is not really an evaluation criteria but is used in the calculation.

Name	Recovery [%]	Reliability	Ease to upgrade	Adaptability to varying flow	Adaptability to varying quality	Ease of O & M	Ease of construction	Ease of demonstration	Power demand	Chemical demand	Odor generation	Impact on ground water	Land requirment	Cost of treatment	Waste (sludge production)	Useful life [years]
NONE																
P1 - Bar screen	100.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	1.00	0.00	3.00	0.00	1.00	1.00	2.00	30.00
P2 - Coarse screen	100.00	3.00	1.00	1.00	1.00	1.00	1.00	3.00	1.00	0.00	2.00	0.00	1.00	1.00	2.00	30.00
P3 - Grit Chamber	100.00	3.00	1.00	3.00	2.00	1.00	1.00	3.00	1.00	0.00	3.00	0.00	1.00	1.00	2.00	30.00
P4 - Equalization Basin	100.00	3.00	1.00	3.00	3.00	3.00	3.00	2.00	1.00	0.00	2.00	0.00	2.00	1.00	1.00	30.00
P5 - Sedimentation without coagulant	99.00	3.00	1.00	2.00	1.00	2.00	2.00	3.00	1.00	0.00	2.00	0.00	3.00	1.00	1.00	30.00
P6 - Sedimentation with coagulant	99.00	2.00	1.00	2.00	3.00	1.00	2.00	3.00	3.00	2.00	2.00	0.00	2.00	2.00	2.00	30.00
P7 - Anaerobic stabilization ponds	100.00	1.00	1.00	2.00	2.00	3.00	3.00	2.00	1.00	0.00	3.00	0.00	3.00	1.00	1.00	15.00
S1 - Activated sludge	99.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	1.00	1.00	0.00	2.00	2.00	3.00	30.00

S1-A - Low Loaded Activated Sludge w/o de-N + Sec Sedim.	99.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	1.00	1.00	0.00	2.00	2.00	3.00	30.00
S1-B - Low Loaded Activated Sludge w de-N + sec. Sedim.	99.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	1.00	1.00	0.00	2.00	2.00	3.00	30.00
S1-C - High Loaded Activated Sludge + Sec. Sedim.	99.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	1.00	1.00	0.00	2.00	2.00	3.00	30.00
S1-D - Extended aeration	99.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	1.00	1.00	0.00	2.00	2.00	3.00	30.00
S2 - Trickling filter with secondary sedimentation	99.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	2.00	0.00	3.00	2.00	3.00	30.00
S3 - Rotating biological contactor (RBC)	99.00	3.00	3.00	2.00	3.00	2.00	2.00	2.00	3.00	0.00	1.00	0.00	2.00	1.00	3.00	30.00
S4 - Stabilization ponds: Aerobic	99.00	1.00	1.00	2.00	2.00	3.00	3.00	2.00	1.00	0.00	3.00	0.00	3.00	1.00	1.00	30.00
S5 - Stabilization ponds: Facultative	99.00	1.00	1.00	2.00	2.00	3.00	3.00	2.00	1.00	0.00	3.00	0.00	3.00	1.00	1.00	30.00
S6 - Membrane bioreactor (MBR)	99.00	3.00	3.00	2.00	3.00	1.00	1.00	2.00	3.00	1.50	2.00	1.00	1.00	3.00	2.00	30.00

T1 - Constructed wetland	100.00	2.00	1.00	2.00	2.00	3.00	3.00	2.00	0.00	0.00	1.00	0.00	3.00	2.00	1.00	30.00
T2 - Enhanced biological phosphorus removal (EBPR)	100.00	2.00	3.00	2.00	2.00	3.00	3.00	1.00	1.00	0.00	2.00	0.00	3.00	2.00	2.00	30.00
T3 -P- Precipitation	100.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	2.00	0.00	0.00	1.00	1.00	2.00	30.00
T4 - Denitrification	100.00	2.00	3.00	2.00	2.00	3.00	3.00	2.00	1.00	0.00	1.00	0.00	2.00	2.00	1.00	30.00
T5 - Dual media filter	100.00	3.00	3.00	2.00	2.00	1.00	2.00	3.00	2.00	1.00	0.00	0.00	2.00	2.00	1.00	20.00
T6 - Microfiltration	90.00	3.00	3.00	2.00	2.00	1.00	2.00	3.00	3.00	1.00	0.00	0.00	1.00	3.00	1.00	20.00
T7 - Ultrafiltration	85.00	3.00	3.00	2.00	2.00	1.00	2.00	3.00	3.00	1.00	0.00	0.00	1.00	3.00	1.00	20.00
T8 - Nanofiltration	83.00	3.00	3.00	2.00	2.00	1.00	2.00	1.00	3.00	1.00	0.00	0.00	1.00	3.00	1.00	20.00
T9 - Reverse osmosis	80.00	3.00	3.00	2.00	2.00	1.00	2.00	3.00	3.00	1.00	0.00	0.00	1.00	3.00	0.00	20.00
T10 - Activated Carbon	100.00	3.00	1.00	1.00	1.00	1.00	1.00	3.00	3.00	1.00	2.00	0.00	1.00	2.00	1.00	20.00
T11 - Ion exchange	90.00	1.00	2.00	1.00	1.00	1.00	2.00	2.00	3.00	3.00	0.00	1.00	1.00	2.00	3.00	30.00
T12 - Advanced oxidation process	100.00	2.00	2.00	3.00	2.00	2.00	3.00	3.00	3.00	3.00	0.00	0.00	1.00	3.00	1.00	30.00

T13 - Soil-aquifer treatment (SAT)	100.00	3.00	2.00	3.00	2.00	3.00	3.00	3.00	1.00	0.00	1.00	2.00	3.00	1.00	0.00	40.00
T14 - Maturation pond	100.00	2.00	1.00	2.00	2.00	3.00	3.00	1.00	1.00	0.00	1.00	0.00	3.00	1.00	1.00	15.00
T15 - Flocculation	100.00	3.00	3.00	2.00	2.00	3.00	3.00	3.00	2.00	3.00	0.00	0.00	1.00	1.00	1.00	30.00
T16 - Electrodialysis	100.00	2.00	2.00	1.00	2.00	2.00	3.00	2.00	3.00	3.00	0.00	0.00	1.00	3.00	0.00	30.00
D1 - Ozonation	100.00	3.00	3.00	3.00	3.00	1.00	2.00	2.00	3.00	0.00	0.00	0.00	1.00	3.00	1.00	15.00
D2 - Chlorine gas	100.00	3.00	2.00	3.00	3.00	2.00	1.00	2.00	1.00	3.00	0.00	1.00	1.00	3.00	1.00	15.00
D3 - Chlorine dioxide	100.00	3.00	2.00	3.00	3.00	2.00	1.00	2.00	1.00	2.00	1.00	1.00	1.00	3.00	1.00	15.00
D4 - Ultraviolet disinfection	100.00	3.00	2.00	2.00	1.00	1.00	1.00	2.00	3.00	0.00	0.00	0.00	1.00	3.00	1.00	15.00

Table 14: References for the tables before

A color code has been used for the references:

White Shading: Data from: Adewumi 2011 that is based on WTRnet 2007.
Blue Shading: The data from Adewumi 2011 and WTRnet 2007 have been reviewed and updated in the frame of an expert workshop that took place at FHNW, on 6.11.2013 in Muttenz, Switzerland. Experts were from FHNW and included: Prof. Thomas Wintgens, Dr Christian Kazner, Dr Rita Hochstrat, Thomas Gross and Emmanuel Oertlé.
(Takashi, Franklin, Leverenz, Tsuchihashi, & Tchobanoglous, 2006)
(Aquarec, Guidelines for Quality Standards for Water Reuse Europe, 2006)

(Mauskar, 2008)
(Hammer & Hammer, 1996)
(El-jafry, Ibrahim, & El-adawy, 2013)
(Rashed Al-Sa'ed, 2012)
Estimated - would need improvement.

Appendix IV: Treatment trains tables

Treatment trains provided are examples from global water reuse and reclamation practices. If applicable the specific re-use purpose has been indicated: blue= re-use for drinking water, green= re-use for agricultural and environmental purpose, orange= re-use for industrial purposes, brown= re-use for urban purposes. Single unit processes of the treatment trains are documented on the basis of the included unit processes in the system and specified (*) in case of additional information on the unit process. Unit processes not yet included in the stage II assessment, are marked in red and have been replaced by a similar existent unit process (or left out in one case- High quality Windhoek).

Case study (Reference)	Name	Process description	Unit Processes										
			1	2	3	4	5	6	7	8	9	10	11
This concept exists as standard in the USA. (Graaf, 2005)	**Simplified Title 22**	*Conventional wastewater treatment, including P and N removal, followed by dual media filtration and disinfection by UV or chlorine. The reuse varies from Urban applications, green landscaping to industrial usage.*	Bar screen	Grit Chamber	Sedimentation with coagulant	Activated sludge	P-Precipitation	Denitrification	Dual media filter	Chlorine gas			
Water reclamation scheme Is Arenas, Sardinia for irrigation(AQUAREC; 2006; Vacca et al., 2005)	**Title 22- Is Arenas**	*Conventionally treated wastewater from Is Arenas WWTP (screening, grit removal, primary settling, activated sludge + sec. sedimentation, NaOCl disinfection) is further treated by a tertiary treatment step and then discharged to Simbirizzi reservoir. It is re-used directly or after storage in the reservoir for irrigational purposes (Vacca et al., 2005).*	Bar screen	Grit removal	Sedimentation without coagulant	Activated slduge	Chlorine dioxide* **Sodium hypochlorite*	Flocculation	Dual media filter	Ultraviolet disinfection			
The Callala water reclamation scheme in New South Wales is designed for irrigation of dairy farm pastures, golf courses and recreational areas (AQUAREC, 2006; Shoalhaven Water: http://shoalwater.nsw.gov.au/education/pdfs/The%20Wastewater%20Process.pdf)	**Title 22- Callala**	*The treatment train of the water reclamation facility consists of preliminary treatment, biological treatment, phosphor removal, sludge treatment, intermediate storage, tertiary treatment and disinfection. The Callala water reclamation scheme is part of the Northern Shoalhaven Reclaimed Water management Scheme (REMS): http://shoalhavenwater.com/projects/rems.htm*	Bar screen* ** Fine screen*	Grit chamber	Equalization Basin	Extended aeration* **Intermittently Decanted Extended Aeration Tank*	Stabilization pond: facultative* **Lagoons for storage*	Dual media filter* **Pressure sand filters*	Chlorine gas				

The tertiary treated effluent of Limassol WWTP is distributed and sold for many purposes such as groundwater recharge and irrigation of golf courses, hotel gardens, olives, deciduous trees and some vegetables. (AQUAREC, 2006)	**Title 22- Limassol**	*The primary treatment includes a pre-treatment unit to remove larger sized particles and to degrade the organic load of the sewage. Additionally, screen, sand and grease collectors before the biological treatment ensure a good degradation in the secondary treatment process which consists of a conventional activated sludge treatment. The tertiary treatment includes sand filtration and disinfection step performed using chlorine gas (<u>only tertiary system is displayed</u>).*	Bar screen	Grit chamber	Sedimentation with coagulant	Activated sludge	Dual media filter	Chlorine gas					
After tertiary treatment, the effluent of Hersonissos WWTP is re-used mainly for agricultural irrigation (and to a minor extent fire protection and landscape irrigation	**Title 22- Hersonissos**	*The WWTP of Hersonissos has been designed to treat both municipal wastewater from the Hersonissos Municipality and septage from the wider area. The WWTP-effluent passes a sand filtration unit followed by a chlorination step.*	Bar screen	Grit chamber	Sedimentation without coagulant	Low loaded activated sludge with de-N and ec. Sedimentation	Dual media filter	Chlorine dioxide* ** Sodium hypochlorite*					
Example from Spain of a water reclamation scheme for park irrigation based on sewage treated in La China WWTP in Madrid (AQUAREC, 2006)	**Title 22- La China**	*The secondary effluent from WWTP La China in Madrid is reclaimed in a tertiary treatment that includes sand filtration and disinfection. After UV disinfection, the reclaimed water is sent to the main reservoirs and then delivered by for park irrigation. The main reservoirs receive chlorination (Chlorine dioxide is used as the secondary disinfectant). (<u>Only tertiary treatment step is displayed here</u>)*	Dual media filter* **Sand filters*	Ultraviolet disinfection	Chlorine dioxide								
Examples of this concept are Water Factory 21, Sydney Olympic Parka and Torrele (Belgium). (Graaf, 2005)	**High Quality**	*Conventional wastewater treatment , including P and N removal, followed by double membrane filtration (MF/UF followed by RO) and final disinfection by UV; eventually also other processes can be applied; the treated water is of so high quality that many applications (industrial, households, etc.) are possible*	Grit Chamber	Sedimentation with coagulant	Activated sludge	P-Precipitation	Denitrification	Ultrafiltration	Reverse osmosis	Ultraviolet disinfection	Chlorine gas	Grit Chamber	
*Wulpen WWTP (Belgium), **Indirect potable re-use** of municipal wastewater (Van Houtte and Verbauwhede, 2008)*	**High quality- Wulpen WWTP**	*Conventional WWTP for municipal wastewater with UF + RO treatment of the WWTP effluent in order to enable indirect potable reuse of the treated wastewater. The filtrations units are complemented by two disinfection steps: by chlorine to control the bio-growth before the UV step and final UV disinfection before the infiltration. The treated water is recharged into a sand dune aquifer, which serves as the source of drinking water for 6 communities.*	Bar screen	Grit chamber	Sedimentation without coagulant	Low Loaded activated Sludge w de-N + sec. Sedim.	Chlorine gas	Ultrafiltration	Chlorine dioxide * ** Chloramination*	Reverse osmosis	Ultraviolet disinfection	Soil-aquifer treatment* **Sand-dune aquifer*	

NEWater Project (Singapore) was implemented to supply industries and augment freshwater resources from reclaimed water, for a total amount of 10% of Singapore daily water consumption. (AQUAREC, 2006)	**High quality-NEWater Project**	*The reclamation process (documented here) consists of a double-membrane treatment of secondary effluent with MF and RO and final disinfection by UV*	Chlorine dioxide * ** Sodium hypochlorite*	Ultrafiltration	Reverse osmosis	Ultraviolet irradiation							
To date, this is the only direct potable reuse project worldwide. It is operating in Windhoek (Namibia) since 2002. It produces potable water from a mixture of pre-treated domestic wastewater effluent and surface water (AQUAREC, 2006)	**High quality-Windhoek**	*The complex treatment train includes coagulation, dual media filtration, ozonation, multi-stage activated carbon adsorption and UF prior to chlorine disinfection. (Source water is raw surface water and pre-treated domestic wastewater)*	(Activated carbon) *If required*	Ozonation	Flocculation	Flotation* *has been left out for Poseidon v3	Dual media filter* **Rapid sand filtration*	Ozonation	Activated carbon* **Biological activated carbon filtration*	Activated carbon* **Granular activated carbon filtration*	Activated carbon* **Powdered activated carbon dosage*	Ultrafiltration	Chlorine dioxide* **Cl_2*
Many examples are available all over Europe. (Graaf, 2005)	**Only disinfection**	*Conventional wastewater treatment, followed by chlorination, enabling the reuse of the treatetd water for irrigation under restricted conditions.*	Bar screen	Grit Chamber	Sedimentation with coagulant	Activated sludge	Chlorine dioxide						
Typical solution for Japanese office buildings is now also introduced in some Europeans sites. (Graaf, 2005)	**Local MBR**	*Small scale treatment of (part of the) wastewater by a package MBR system with reuse of the water in the direct neighbourhood (as toilet flush water).*	Membrane bioreactor (MBR)										
Examples are present in the Mediterranean area (Israel). (Graaf, 2005)	**Soil treatment**	*Conventional wastewater treatment, including P and N removal, followed by infiltration through large ground areas; the final water can be reused for unrestricted irrigation.*	Bar screen	Grit Chamber	Sedimentation with coagulant	Activated sludge	-P-Precipitation	Denitrification	Soil-aquifer treatment (SAT)				

The Dan region (Israel) infiltrates treated wastewater in the soil (SAT). Water is stored in local reservoirs and post chlorinated before usage for agricultural irrigation (AQUAREC, 2006)	**Soil treatment- Dan region**	*Effluent from the Dan region WWTP is conveyed to four recharge basins covering a total area of 80 ha. The infiltration into the groundwater is carried out by alternate flooding and drying. After the SAT system the reclaimed water has to be chlorinated to maintain bacteriological quality the long distribution lines. Approx. 200 recovery wells, located 300 to 1500 m from the recharge basins, pump the recharged water from a depth of 100 to 200 m. Water recovered from the SAT system is of extremely high quality and can be used for unrestricted agricultural irrigation.*	Bar screen* ** Fine screen*	Grit chamber	Low loaded active sludge with de-N and Sec. Sedim.* ** Activated sludge, nitrification-denitrification*	Soil Aquifer treatment	Chlorine gas						
Applications are present in Northern Europe (Netherland) as well as Southern Europe (Spain). (Graaf, 2005)	**Wetlands**	*Conventional wastewater treatment, including P and N removal, followed by constructed wetlands as a natural polishing step. Reuse can be done in nature conservation or agriculture.*	Bar screen	Grit Chamber	Sedimentation with coagulant	Activated sludge	P-Precipitation	Denitrification	Constructed wetland				
Constructed Wetland - Masaya Pilot Plant Nicaragua (Gauss, 2008)	**Constructed Wetland**		Bar screen	Grit Chamber	Constructed wetland								
Treated effluent from Arcata WWTP (California, USA), is discharged into 'enhancement wetlands', which are part of the Arcata Marsh and Wildlife Sanctuary (AQUAREC, 2006)	**Wetlands- ARCATA Wildlife sanctuary**	*The first treatment steps at the Arcata WWTP consist of bar screens, a grit chamber and 2 settling tanks for primary treatment. Secondary and partial tertiary treatment is accomplished by 2 oxidation ponds followed by 3 parallel FWS (Free water surface) wetlands that were constructed in 1985. (After chlorination and de-chlorination, part of the wastewater is released while another part flows into three so-called 'enhancement FWS wetlands'). The 'enhancement wetlands' together with some additional landscape features, are referred to as the Arcata Marsh and Wildlife Sanctuary*	Bar screen	Grit chamber	Sedimentation without coagulant	Anaerobic stabilization ponds	Chloriine dioxide* * Chlorination and de-chlorination	Constructed wetlands					

Example from Spain with the goals to feed water of sufficient quality to the Cortalet lagoon in a Natural Reserve and to stimulate the recovery and establishment of local flora and fauna (AQUAREC, 2006; Sala, et al., 2004).	**Wetlands- ELS AIGUAMOLLS DE LÊMPORDÀ**	*Empuriabrave WWTP (Costa Brava, Spain) is of the extended aeration type and consists in its current form o f a mechanical pre-treatment step and then two parallel treatment lines each comprising a biological reactor, a clarifier and three effluent polishing ponds. A chemical treatment for phosphorus removal has recently been added. Further treatment is then achieved by means of a wetland system (3 parallel cells) that started operation in 1998.*	Bar screen	Grit chamber	Extended aeration	P-precipitation* ** P-removal: not further specified*	Maturation pond	Constructed wetland						
Example from Belgium of a water reclamation scheme. Built to overcome flooding problems but serves now as valuable habitat for wildlife (AQUAREC, 2006)	**Wetlands- WWTP Liedekerke**	*After conventional treatment the secondary effluent of the WWTP Liederkerke (Belgium) is guided into a 1.66km long, 2.5 wide free-water surface (FWS) wetland followed by a lagoon. Finally the effluent is discharged in the River Dender (Only tertiary treatment step is displayed here). The FWS wetland was planted with Phragmites australis.*	Constructed wetland	Maturation pond* **Lagoons not further specifed*										
Typical application for Mediterranean countries with moderate treatment facilities. (Graaf, 2005)	**Lagooning**	*Treatment of wastewater by lagooning (several types in series), occasionally followed by chlorination; reuse of the effluent by (very) restricted irrigation.*	Maturation pond	Maturation pond	Maturation pond	Maturation pond	Chlorine dioxide							

The chlorinated effluents from two WWTPs in Haifa, Israel are purified in retention reservoirs from where water is filtered and chlorinated and either sent to irrigation or to peripheral reservoirs (AQUAREC; 2006)	**Hakishon maturation ponds**	*The Hakishon unrestricted irrigation effluent recovery systems is based mainly on receiving effluents from Haifa and Afula WWTPs and some flood water, longterm storage, and supplementary treatment of the effluent (by surface straining filtration and chlorination).* *Treatment train Haifa WWTP: Built to perform nitrification-denitrification together with organic removal (<u>this treatment train has been included, asWWTP has higher capacity)</u>* *Treatment train Afula WWTP: Operates on the extended aeration principle.* *The chlorinated effluents from the two WWTPs are purified in a main reservoir with a retention time of at least 60 days (where it is also mixed with stormwater). From the reservoir, water is filtered and chlorinated and sent to irrigation or to peripheral reservoirs.*	Bar screen	Grit chamber	Sedimentation with coagulant	Low loaded activated sludge with de-N & secondary sedimentation	Chlorine dioxide* ** Chlorination: not further specificed*	Maturation pond	Dual media filtration* **Filtration: Not further specified*	Chlorine dioxide* ** Chlorination: not further specficed*			
One of the typical storage and polishing lagoons case studies. Treated water of WWTPs on the island (Noirmoutier island, France) is polished in maturation ponds and reused for potatoes growing (AQUAREC, 2006)	**Noirmoutier island lagoon storage**	*For agricultural irrigation the treated wastewater from three WWTP (main one: La Salaisière WWTP) on the island is polished in maturation ponds. La Salaisiére receives effluents of three municipalities as is composed of activated sludge systems and aerated lagoon systems. The treated effluents from all WWTP flow into a lagoon-storage system, four lagoons in series with a total volume of 196300 m³ which is used as tertiary treatment and storage facility before irrigation. Stored water that is not used for irrigation is disposed to the sea.*	High loaded active sludge + sec. Sedimentation	Anaerobic stabilization ponds:	Anaerobic stabilization ponds::	Stabilization ponds: facultative	Stabilization ponds: facultative	Maturation pond	Maturation pond	Maturation pond	Maturation pond		
Example from Australia of water reclamation for horticultural (unrestricted) irrigation (AQUAREC, 2006)	**Bolivar**	*Bolivar WWTP effluents are re-used for horticultural irrigation in the Virginia area (Australia). Main crops irrigated are root and salad crops, brassicas, wine grapes and olives (=unrestricted irrigation). Sewage from the Adelaide metropolitan areas is treated in Bolivar WWTP by activated sludge process. The effluents from secondary treatment were then held in shallow aeration lagoons for a minimum of 6 weeks, before passing through a dissolved air flotation and dual media filtration process at the water reclamation plant. Here, the effluents discharge via a chlorinator into a balancing storage before being pumped into the pipeline for distribution for horticultural irrigation.*	Stabilization ponds: Aerobic	Flocculation* **Flotation*	Dual media filtration	Chlorine dioxide* ** Chllorination not further specified*							
Example from Australia of water reclamation for restricted irrigation (AQUAREC, 2006)	**Picton lagoons**	*Picton water reuse scheme produces reclaimed water used for growing Lucerne and ryegrass/clover pastures and a woodlot. The water reclamation process includes intermittently decanted extended aeration lagoons, operated in a manner to allow nitrogen and phosphorus levels in the effluent suitable for agriculture and silviculture irrigation, followed by sand filters and UV disinfection. Treated effluent is stored in a dam where a minimum 10 day retention time achieves required water quality for crop irrigation.*	Stabilization ponds: Aerobic	Dual media filter* ** Sand filters*	Ultraviolet disinfection	Maturation pond							

New concept, which is investigated in several places (Netherland, China, Israel). (Graaf, 2005)	**Direct membrane filtration**	*Micro or Ultra Filtration of raw wastewater followed by agricultural applications. (Graaf, 2005)*	Bar screen	Grit Chamber	Ultrafiltration								
Parrow is a northern suburb in the city of Cape Town, Western Cape Province, South Africa. Parrow WWTW has a design capacity of 1.2Ml/d but was using 85% of its capacity in 2007. (Adewumi, 2011)	**Case study Parrow**	*In April 2007, the Parrow WWTW treatment train included extended aeration, activated sludge, maturation pond and chlorine gas disinfection. All the effluent from the treatment plant were used for irrigation of Parrow golf course and football fields. It can be upgraded to supply treated effluent to irrigate colleges and different sport complexes.*	Bar screen	Grit Chamber	Sedimentation with coagulant	Activated sludge	Maturation pond	Chlorine gas					
Some case studies from Latin-America will be included here in the future	**Phosphor Removal**	*Iowa Hill Wastewater Reclamation Plant (EPA, Advanced Wastewater Treatment to Achieve Low Concentration of Phosphorus, 2007)*	Bar screen	Grit Chamber	Activated sludge	Activated sludge	Flocculation	Microfiltration	Chlorine gas				
Some case studies from Latin-America will be included here in the future	**Denitrification**	*Lee County Florida (EPA, Municipal Nutrient Removal Technologies Reference Document, Volume 1, 2008)*	Bar screen	Grit Chamber	Stabilization ponds: Aerobic	Denitrification	Chlorine gas						
Some case studies from Latin-America will be included here in the future	**N and P removal**	*Western branch wastewater treatment plant (EPA, Municipal Nutrient Removal Technologies Reference Document, Volume 1, 2008)*	Bar screen	Grit Chamber	High Loaded Activated Sludge + Sec. Sedim.	Denitrification	Dual media filter	Chlorine gas					

Domestic wastewater treatment in Latin America - Trickling Filter (Wett & Buchauer , year?)	**Domestic WWT LA**		Bar screen	Grit Chamber	Sedimentation without coagulant	Trickling filter with secondary sedimentation							
Agricultural Reuse (Wett & Buchauer, year?)	**Agricultural Reuse**		Bar screen	Grit Chamber	Sedimentation without coagulant	Low Loaded Activated Sludge w/o de-N + Sec Sedim.	Chlorine gas						
Urban Restricted Reuse with P-precipitation and Chlorination (Takashi, Franklin, Leverenz, Tsuchihashi, & Tchobanoglous, 2006)	**Urban Restricted Reuse 1**		Bar screen	Grit Chamber	Sedimentation without coagulant	Low Loaded Activated Sludge w de-N + sec. Sedim.	P-Precipitation	Chlorine dioxide					
Urban Restricted Reuse with P-precipitation and Chlorination (Takashi, Franklin, Leverenz, Tsuchihashi, & Tchobanoglous, 2006)	**Urban Restricted Reuse 1**		Bar screen	Grit Chamber	Sedimentation without coagulant	Low Loaded Activated Sludge w de-N + sec. Sedim.	Microfiltration	Ultraviolet disinfection					
(Takashi, Franklin, Leverenz, Tsuchihashi, & Tchobanoglous, 2006)	**Recreational use**		Bar screen	Grit Chamber	Sedimentation without coagulant	Membrane bioreactor (MBR)	Enhanced biological phosphorus removal (EBPR)	Ultraviolet disinfection					

Landscape Irrigation (Takashi, Franklin, Leverenz, Tsuchihashi, & Tchobanoglous, 2006)	**Landscape irrigation**		Bar screen	Grit Chamber	Sedimentation without coagulant	Loaded Activated Sludge w/o de-N + Sec Sedim.	Microfiltration	Electrodialysis	Chlorine dioxide				
Groundwater recharge, surface water augmentation (Takashi, Franklin, Leverenz, Tsuchihashi, & Tchobanoglous, 2006)	**Groundwater Recharge**		Bar screen	Grit Chamber	Sedimentation without coagulant	Low Loaded Activated Sludge w/o de-N + Sec Sedim.	Microfiltration	Reverse osmosis	Advanced oxidation process				
Example for Water Reuse System for Industrial Purposes. Aquapolo Project at the Santo Andre Wastewater Treatment Plant in the Sao Paulo Metropolitan Region, Sao Paulo (SPMR) – Brazil (Mierzwa, 2014)	**Aquapolo Project**	*This treatment train was an adaptation for the implementation of an industrial water reuse scheme. The main issue was to use the treated effluent from a high loaded activated sludge process as a source for the reuse scheme. Because effluent nitrification was not considered in the original project, it was necessary to implement a MBR system capable to accomplish the nitrification and denitrification processes.http://www.watertoday.org/Article%20Archieve/Koch18.pdf*	Bar screen	Grit Chamber	Sedimentation without coagulant	High Loaded Activated Sludge + Sec. Sedimentation	MBR *(with nitrification and denitrification*	Reverse osmosis	Chlorine dioxide				
Example for Water Reuse for industries in Brazil. This reuse scheme is used by SABESP to supply re-used water (from two wastewater treatment plants, Jesus Neto and Parque Novo Mundo) for industrial purposes in Sao Paulo, Brazil. (Mierzwa, 2014)	**SABESP water reuse**	*The presented scheme is a basic treatment process train for water reuse. The main issue is the effluent final ammonia concentration, because the proposed system did not perform the nitrification step. The main consequence is the higher chlorine dosage to reach the breakpoint.*	Coarse screen	Grit Chamber	Sedimentation without coagulant	High Loaded Activated Sludge + Sec. Sedimentation	Dual media filtration *(with preivious coagulation)*	Dual media filter * **Catridge filtration*	Chlorine dioxide* **Sodium hypochlorite*				
Example from Belgium re-using water to produce cooling water for industrial purposes (AQUAREC, 2006)	**Tienen**	*A pharmaceutical company (Tienen) makes use of treated municipal wastewater for cooling water. Secondary treated effluent is ozonated for disinfection. If the amount of reclaimed wastewater is too low or temperature too high, it is mixed with groundwater before usage. The WWTP consists of low loaded activated sludge system with enhanced biological phosphorus removal.*	Low loaded activated sludge with de-N and secondary sedimentation	Enhanced biological phosphorus removal	Ozonation								

Example from California re-using water to produce boiler water (steam for the power station turbines) for industrial purposes (AQUAREC, 2006)	**West Basin El Segundo**	*The Reclamation plant in El Segundo (California, USA) treats the secondary effluent from Los Angeles Hyperion WWTP to produce four types of drought proof reclaimed water. One of the streams is ultra-pure reclaimed water produced by a double membrane system (microfiltration and reverse osmosis) for the use as boiler feed water in the petroleum industry.*	Bar screen	Grit removal	Sedimentaion with coagulant* *Coagulation and flocculation*	Dual media filter* **Filtration not further specified*	Chlorine dioxide* **Chlorination not further specified*	Microfiltration	Reverse osmosis				
Example from Italy, re-using water for textile industries as process water (AQUAREC, 2006).	**Prato water reclamation plant-textile industry**	*Secondary effluent (municipal wastewater) is reclaimed by flocculation, ozonation, coagulation, sand filtration and biological activated carbon*	Flocculation	Ozonation	Sediment with coagulant	Dual media filter* **Sand filtration*	Activated carbon* **Biological activated carbon*						
Example from California, re-using water for pulp and paper industry processes (AQUAREC, 2006)	**Pomona water reclamation plant-pulp and paper**	*Six pulp and paper mills use reclaimed water from Pomona water reclamation plant in their process operation. The treatment includes biological oxidation, alum coagulation, filtration and disinfection.*	Activated sludge	Sedimentation with coagulant	Activated carbon* **Activated carbon filters*	Chlorine dioxide* **Disinfection not specified*							
*This is a reuse scheme in the SPMR for **urban water reuse** (Mierzwa, 2014)*	**Valville II**	*This is the first water reuse scheme in Brazil with a distribution network specific for reuse water. It was implemented in a residential condominium.* *The reuse water is applied for non-potable applications, such as toilet flush, irrigation, and floor cleaning.* *In this water reuse scheme, there is the addition of a colorant to the final water in order to avoid the undue use.*	Bar screen	Grit chamber	Anaerobic stabilization pond* *UASB	Trickling filter with secondary sedimentation	P-Precipitation	Dual media filter	Ultraviolet disinfection	Chlorine dioxide* **Sodium hypochlorite*			
*This is a reuse scheme in the SPMR for **urban water reuse** (Mierzwa, 2014)*	**Mundo Apto**	*The reuse water is applied for toilet flushing, irrigation, and floor cleaning. This water reuse scheme was installed in, at least, five apartment buildings at the SPMR. This water reuse scheme was originally designed with a rotating biological contactor for BOD removal and a filtration system. However, the entrepreneur, based on the investment costs, decided to buy and install the specific treatment train. Because of this decision, the treated water cannot be stored for more than one day before being reused, because odours problems.*	Equalization Basin	Sedimentation without coagulant	Dual media filter	Chlorine dioxide* **Sodium hypochlorite*							

Emmen WWTP (The Netherlands), Reuse of municipal WWTP effluent to ultrapure water for the production of steam (http://nwtr.nl/du/puurwaterfabriek.php)	**Puurwaterfabriek**	*Conventional WWTP for municipal wastewater is treated in several membrane processes to produce ultra-pure water. This water is suitable for production of stream without leaving behind deposits that can damage boilers, turbines and pumps. The capacity of the plant is 10'000 m³/day*	Bar screen	Grit chamber	Sedimentation without coagulant	Low Loaded Activated Sludge w de-N + Sec. Sedim.	Dual media filter* *Rotary filter	Ultrafiltration	Activated Carbon	Reverse osmosis	Electriodialysis		
Example of urban water reuse scheme in Sydney (Australia) (AQUAREC, 2006).	**Rouse Hil (Sydney Water)**	*The primary treatment includes a fine screen, grit removal and a primary clarifier. The activated sludge system includes nitrification, denitrification and biological phosphorous removal. The tertiary treatment includes flocculation, tertiary sedimentation and filtration. A part of the effluent is further upgraded in the recycling plant by microfiltration as well as sodium hypochlorite dosing. He water is stored in three storage tanks. The recycled water is used for gardening, car washing and toilet flushing.*	Bar screen	Grit removal	Sediemnation without coagulant* *Sedimentation not further specified	Low loaded activated sludge with de-N & secondary sedimentation	Flocculation	Dual media filter* ** Filter not further specified*	Microfiltration	Chlorine dioxide* ** Sodium hypochlorite*			
One of the largest in-building recycling schemes for reclaiming water in Europe (Greenwich, United Kingdom) for toilet and urinal flushing. Daily around 500 m³ water is reclaimed (AQUAREC, 2006)	**Millennium Dome**	*The Millenium Dome reclaims water consisting of greywater (10%), rain water (19%) and groundwater (71%). Several technologies from very innovative membrane treatment to natural wetlands are utilized to reclaim the water. Rain water is treated by 2 reedbeds and a storage lagoon. In the reed bed, Phragmites auralies remove contaminants from the rainwater (filtration and biological process). Greywater is treated by a biological aerated filter (BAF) and groundwater is held in contact with hydrogen peroxide, and granular activated carbon (GAC). In the final step greywater, rainwater and groundwater are passed through an ultrafiltration and reverse osmosis membrane and are finally disinfected by chlorine.*	Trickling filter with secondary sedimentation* ** BAF*	Activated carbon* ** GAC*	Constructed wetland	Ultrafiltration	Reverse osmosis						
Potable reuse of treated wastewater in Chanute, Kansas. USA (Asano et al., 2006, p. 1348)	**Chanute**	*The Neosho River is dammed below the outfall of the sewage treatment plant. The treated sewage is disposed to the river channel behind the water treatment dam (where river water stored in the river channel gets mixed with treated sewage). The impounding reservoir serves very effectively as a waste stabilization pond (17d retention).*	Bar screen	Grit chamber	Activated sludge	Trickling filter with secondary sedimentation	Chlorine dioxide* **Chlorine*	Stabilization pond: facultative					
Example of full-scale direct injection facility for groundwater recharge, El Paso, Texas, USA (Asano et al., 2006, p.1292	**El Paso full-scale direct aquifer injection**	*Primary effluent enters a two-stage biophysical process which combines activated sludge with powdered activated carbon adsorption. This step of treatment is designed for organics removal, nitrification, and denitrification. A lime treatment steps follows to remove phosphorous and heavy metals, to inactive viruses and to soften the reclaimed water. Turbidity removal is provided by sand filter, and disinfection is provided by ozonation. The final product water is passes through a granular activated carbon filter for final polishing before release to storage.*	Activated sludge	Activated carbon	P-Precipitation	Dual media filter* **Sand filter*	Ozonation	Activated carbon					

Mesa city (Arizona, USA) has two reclamation plants. Both plants reclaim water for re-use on golf courses, crop irrigation, industrial uses, freeway landscape watering, and for groundwater recharge (Asano et al., 2006), p. 1281	**Mesa water reclamation**	*Northwest Water Reclamation plant has treatment that includes secondary treatment with nutrient removal, filtration, clarification, and disinfection. Reclaimed water is discharged to two recharge sites and to the Salt river, which also recharges the aquifer.*	Bar screen	Grit chamber	Sedimentation without coagulant	Activated sludge	Dual media filter* **Filtration: not specified*	Chlorine dioxide* *Disinfection: not specified	Soil-Aquifer treatment				
The Santee recreational lakes project developed initially as an economic alternative to wastewater disposal in the Pacific Ocean. The series of lakes are supplied with reclaimed water and used for various recreational activities like fishing, boating, and camping. (Asano et al., 2006, pp.	**Santee lakes San Diego**	*Primary sedimentation system with sludge digestion and pond treatment with effluent placed in two constructed lakes. Activated sludge plant with denitrification capability is available. Effluent is then discharged to infiltration basins. The tertiary plant is consisting of a coagulation and flocculation system using alum and a lamella settler for turbidity and excess phosphorous removal followed by a denitrification filter using methanol as a carbon source. Chlorine disinfection is applied to all effluent. Effluent to be used in the lake system is de-chlorinated with sulphur dioxide.*	Sedimentation without coagulation	Low loaded activated sludge with de-N and secondary sedimentation	Dual media filter* **Iinfiltration basins*	P-Precipitation	De-nitrification	Chlorine dioxide* ** Chlorine not further specificed*					

Appendix V: Cost estimation tables

Unit process	Regression coefficient	P1 - Bar screen	P2 - Coarse screen	P3 - Grit Chamber	P4 - Equalization Basin	P5 - Sedimentation without coagulant	P6 - Sedimentation with coagulant	P7 - Anaerobic stabilization ponds	S1 - Activated sludge	S1-A - Low Loaded Activated Sludge w/o de-N + Sec Sedim.	S1-B - Low Loaded Activated Sludge w de-N + sec. Sedim.	S1-C - High Loaded Activated Sludge + Sec. Sedim.	S1-D - Extended aeration	S2 - Trickling filter with secondary sedimentation	S3 - Rotating biological contactor (RBC)	S4 - Stabilization ponds: Aerobic	S5 - Stabilization ponds: Facultative	S6 - Membrane bioreactor (MBR)	T1 - Constructed wetland	T2 - Enhanced biological phosphorus removal (EBPR)
Construction cost	B	0.512377	0.5138	0.446445	0	0.5146	0.468	0.896305	0	0.7209	0.7205	0.75104	0.75104	0.7361	0.7135	0.813302	0.844919	0.75	0.392608	0.522899
	C	4.044137	6.40085	9.13003	0	16.16125	29.05172	0.301345	0	7.787028	8.217256	4.859582	4.859582	5.055175	4.56597	1.108493	1.050282	8.193527	9.716189	1.700555
Land requirements	B	0.516602	0.357506	0.400943	0	0.947658	1.018748	1.000779	0	0.987576	1.003578	1.06568	1.06568	0.98438	0.984624	1.365297	0.903106	0.972166	0.957868	0.964509
	C	0.000108	0.00014	0.000119	0	5.17E-06	1.42E-06	0.00031	0	3.05E-05	3.21E-05	1.91E-05	1.91E-05	1.38E-05	2.09E-06	5.56E-05	0.001703	7.5E-06	0.002216	4.92E-06
Energy requirements	B	0	0	1.007629	0	0.998126	0.998126	0	0	0.985572	1.000008	0.999984	0.999984	1	1	0	0	1	0.999962	1.000815
	C	0	0	4.135609	0	1.303594	1.303594	0	0	181.3654	183.3218	91.67819	91.67819	55	55	0	0	219	36.678	1.821608
Labour requirements	B	0	0	0	0	0	0.054688	0.424123	0	0.144917	0.144917	0.190664	0.190664	0.190664	0.19172	0.416493	0.945928	0.715122	0.238406	0
	C	4	4	8	0	8	12.84873	1.400421	0	159.8641	159.8641	87.21185	87.21185	87.21185	86.87102	0.12485	0.026548	1.154627	6.142528	0
Other O&M	B	0.487562	0.516725	0.443285	0.78685	0.525599	0.518036	0.860822	0	0.928824	0.921522	1.204618	1.204618	0.696239	1.12612	0.839442	0.796592	0.693806	0.615594	0.58907
	C	0.46051	0.623897	0.900323	0.17251	0.288647	1.562384	0.028052	0	0.076386	0.077983	0.008541	0.008541	0.490095	0.033488	0.034076	0.033291	1.047075	0.449722	0.05249

Unit process		T3 -P-Precipitation	T4 - Denitrification	T5 - Dual media filter	T6 - Microfiltration	T7 - Ultrafiltration	T8 - Nanofiltration	T9 - Reverse osmosis	T10 - Activated Carbon	T11 - Ion exchange	T12 - Advanced oxidation process	T13 - Soil-aquifer treatment (SAT)	T14 - Maturation pond	T15 - Flocculation	T16 - Electrodialysis	D1 - Ozonation	D2 - Chlorine gas	D3 - Chlorine dioxide	D4 - Ultraviolet disinfection	
Construction cost	B	0.145001	0.145001	0.593608	0.600001	0.600001	0.844997	0.844997	0.880302	0.999991	0.650751	0.99993	0.798678	0.196785	0.999991	0.732601	0.639202	0.639202	0.739904	
	C	12.14062	12.14062	3.096288	5.764633	5.764633	1.012361	1.012361	1.520823	0.177783	1.541952	0.024184	0.408424	29.82688	0.177783	2.481176	4.154137	4.154137	1.946311	
Land requirements	B	0	0	0.288012	0.584242	0.584242	0.498218	0.498218	0.981242	1.000271	1.00844	0.913122	0.999307	-2.2E-32	1.000271	0.495343	0.316981	0.316981	0.876243	
	C	0.0075	0.0075	0.019249	0.000144	0.000144	0.000151	0.000151	2.68E-06	7.27E-06	1.43E-06	6.95E-06	0.00035	0.0033	7.27E-06	6.56E-05	0.004053	0.004053	2.72E-05	
Energy requirements	B	0.996376	0.996376	0.99987	0.999957	1	0.999976	1	1	0.950291	0.888885	1	0	1.000063	1	0.999974	0.999787	0.999787	1	
	C	0.377218	0.377218	27.40468	91.28175	109.5	164.2818	365	182.5	147.7337	1873.141	87.6	0	5.299073	1058.5	208.0859	18.28174	18.28174	87.6	
Labour requirements	B	0	0	0.055642	0.184421	0.184421	0.184421	0.184421	0.342606	0.236782	0.264711	0.054727	0.305671	0	0.236782	0.264711	0.302861	0.302861	0.303461	
	C	0	0	51.1519	57.01982	57.01982	57.01982	57.01982	10.22092	17.4136	13.85992	108.4598	2.504125	24	17.4136	13.85992	4.684957	4.684957	4.68509	
Other O&M	B	0.999459	0.999459	0.006866	1.072667	1.076042	1.353971	1.095594	0.824784	1.097682	1.265371	1.050556	0.842496	0.401581	1.097682	1.074854	0.566581	0.566581	1.149077	
	C	0.003026	0.003026	13.02714	0.015008	0.014016	0.001879	0.009753	0.180252	0.005254	0.002112	0.024053	0.026887	0.737011	0.005254	0.001872	0.652346	0.652346	0.000657	

Annex to COROADO Deliverable 4.2

Contents

1.1 Input data used for the PCRGLOBWB model

Category	Variables (units)	Data source	Remarks	Adaptations for the local domain
Climate forcing	Precipitation Temperature Reference potential evaporation	CRU TS 2.1 (New et al., 2001, 2001) (1901-2002) CRU CLIM 1.0 (1961-1990) ERA40 (1958-1978) ERA-Interim (1979-2010)	The CRU TS 2.1 dataset was downscaled from monthly to daily values with the ERA Reanalysis datasets (Ludovicus P. H. Van Beek, 2008)	
Terrain	Terrain slope Elevation	Hydro1K data set [USGS Eros Data Center, 2006a]		
Hydrography	Areas of lakes, wetlands and reservoirs Drainage density Channel geometry	GLWD inventory [Lehner and Döll, 2004] VMAP0 [FAO, 1997] Global River Bankfull Width and Depth Database (Andreadis, Schumann, & Pavelsky, 2013)		
Land cover	Crop factors for different land surfaces Vegetation cover Maximum interception storage	CRU CLIM 1.0 GLCC version 2 USGS Eros Data Center [2002] Irrigated crops: Döll and Siebert [2002]	Crop factors are used in the model to convert the monthly reference potential evaporation into vegetation specific values	Land cover information was refined using land use maps from the case study areas For urban areas, maximum interception storage was estimated as 1.29 km.m-2 (or 0.00129 m), based on (Wouters, Demuzere, Ridder, Lipzig, & Vogel, 2012)
Soils & substrate	Soil hydrological properties Soil thickness Aquifer properties Groundwater residence time	FAO gridded soil map of the world [FAO, 1998] Lithological map of the world [Dürr et al., 2005]		

1.2 Comparison of model results for the local domain with observations

A comparison between model results in all the study sites and observations can be found in the table below. It is important to note that water abstraction is not modelled, and that model results refer to monthly or annual blue water flows, not to stocks. PCR-GLOWWB gives useful insight in the potentially available amount of blue water, based on the biophysical characteristics of the region. Human-induced water extractions can be influenced by policy measures, and are difficult to model for reasons explained in Chapter 3 of the main report. Consequently, some overestimation of the modelled discharge compared to the observed discharge might be expected.

Discharge comparison as modelled with the PCRGLOBWB model and compared to data as provided by study sites or through literature.

Location	Location for comparison in the area	Mean annual discharge as modelled by PCRGLOBWB model	Mean annual discharge from Study site (observed data)	Reference
		$m^3 s^{-1}$		
Argentina	Suquia river	11-20	9	
Brazil	Guarapiranga and Billings reservoir	31.4-43.8	115	Sao Paulo State Hydric Resources Situation report 2011
Chile	Copiapo city	0.26-3.09	1.1-1.4	
Mexico	Reynosa city	35.1-66.0*	32.7-52.7	

* The large value of 243 m3 s-1 in Mexico is taken out from the average due to the large inflow from the precipitation during hurricane Alex.

Mexico

The point of discharge simulated in the PCRGLOBWB model is located close to the city of Reynosa, and the discharge modelled around 70 $m^3 s^{-1}$, implies a mean discharge of 2'200 hm^3/year, when compared to the observed discharge values with a mean discharge above 2'000 hm^3, the order of discharge in a year is similar. Withdrawal from surface water is estimated to be 31 m3 s-1, of which agricultural use is the largest part (29 m3 s-1) which would be almost 1000 hm3 (Del 2.1).

Brazil

According to PERH (2007) the average discharge for the region Alto Tiête River Basin is a bit lower than simulated by the PCRGLOBWB model (84 m^3/s). Their region Alto Tiête corresponds more or less with the modelled study area catchment. Unfortunately it is unknown to which period the PERH results refer, and how the climatic conditions in this period relate to our period. The range of discharge values Mortatti et al. (2008) reported for the Tiête River at the Tiête city sampling station are between 55 and 353 m^3/s (average 155 m^3/s). Although their catchment area was larger (9060 km^2) than our study area, the order of magnitude of the regional and local model simulations seems plausible, particularly when you take into account the absence of human-induced water extractions in the model results.

Chile

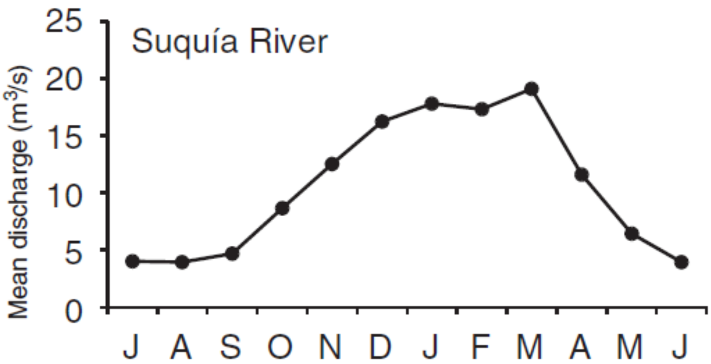
Sources on the internet[1] confirm that the discharge of the Copiapó River is low. According to Bitrán et al. (2011) the biggest flow (1.8 m^3/s) is located at the west side of the Lautaro reservoir (southeast of Copiapó city). To the west of Copiapó (in the direction of the outlet) the river is usually dry with an average flow close to zero (Bitrán et al., 2011). This decrease in river discharge is caused by consumption (mainly by the agricultural sector). Unfortunately, the

[1] http://en.wikipedia.org/wiki/Copiap%C3%B3_River;
http://www.ineatacama.cl/archivos%5Cfiles%5Cpdf%5CDivisionPoliticoAdministrativa%5Catacama.pdf

model is not able to take into account human-induced water extractions , so (part of) the overestimation of the modelled discharge can be explained.

Argentina

The figure below shows the discharge of the Suquía river according to Pasquini (2006) downstream of the San Roque reservoir, near the locations of the water supply points for which discharge time series were generated with the PCRGLOBWB model.



Mean monthly discharge in the Suquía river in Argentina (Pasquini, 2006).

On average these discharges are 9 $m^3 s^{-1}$. Also Pasquini, 2012 found an average discharge of 9 $m^3 s^{-1}$ for the San Roque station (year 1926-1998), there are also indications that the discharge has increased significantly in the past 70 years, which can be found by the rise in height of lake Mar Chiquita in which the Suquía river leads. From deliverable 2.1 it is estimated that both the Suquía river and the river which flows from the Los Molinos reservoir (Arroyo La Canadá) give an average discharge of almost 13 $m^3 s^{-1}$. The combined simulated discharge of Los Molinos and San Roque are higher than the 13 $m^3 s^{-1}$, however the withdrawal of water for the agricultural region south of Cordoba is not included in this analyses. Water withdrawal in Cordoba city is estimated to be 4.4 $m^3 s^{-1}$. It can be therefore be considered that the PCRGLOBWB model is applicable to the Argentinian case study.

1.3 Climate change scenarios for the local domain

These figures are included under Annex 1.4.

1.4 Water availability assessment at the local scale

Scenarios for water availability at the local scale for the case study sites under climate change.

1.4.1 Brazil

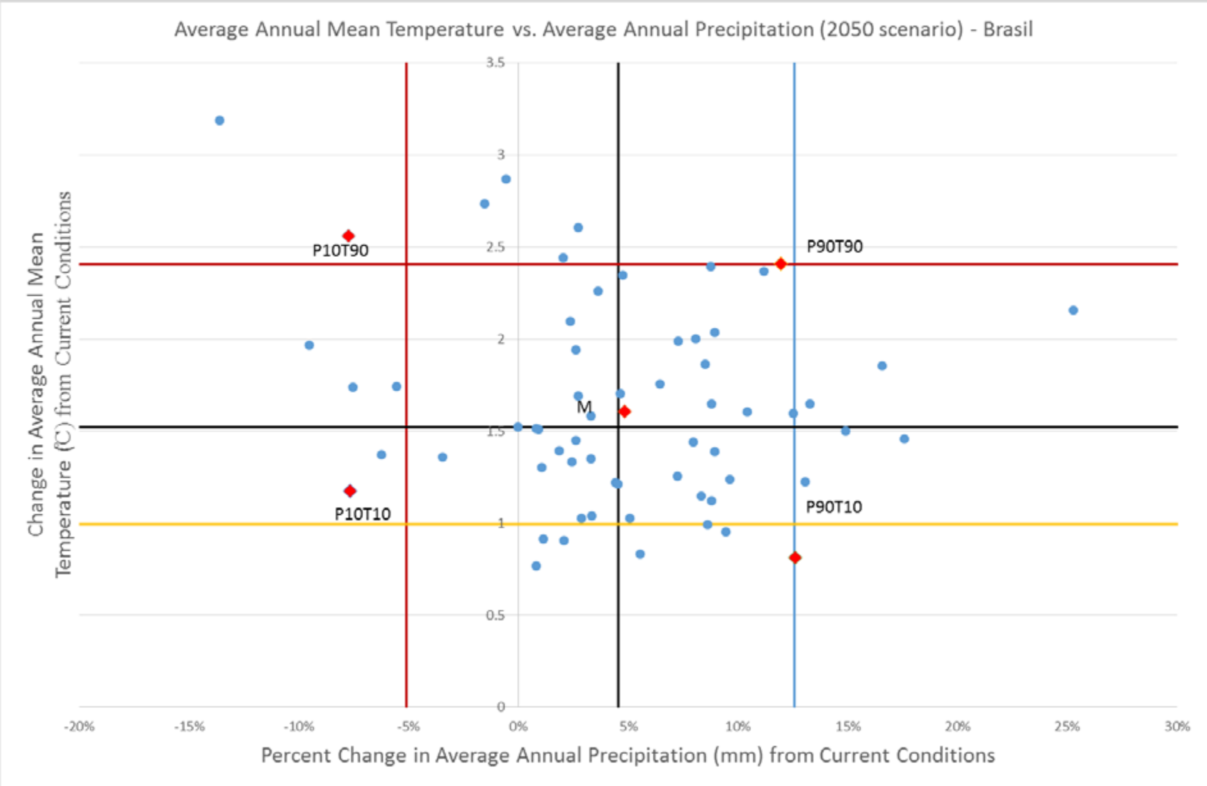


Figure 1. Five future climatic models as selected from 63 models for Upper Tiête River Basin, Brazil.

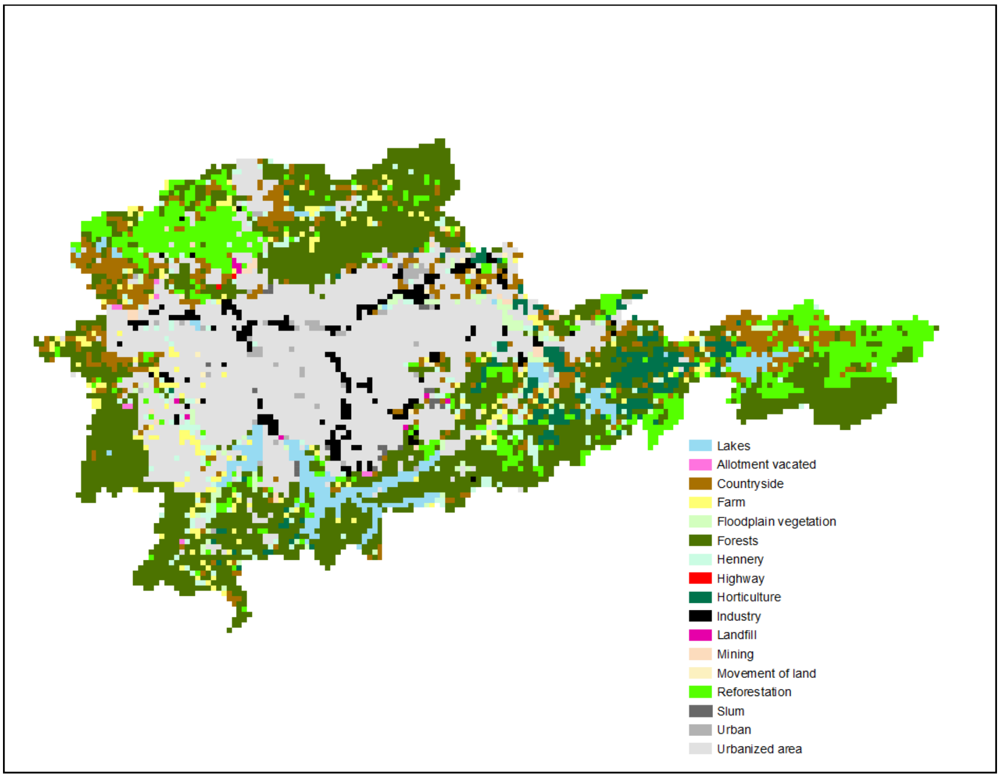


Figure 2. Land use in Upper Tiête River Basin, Brazil

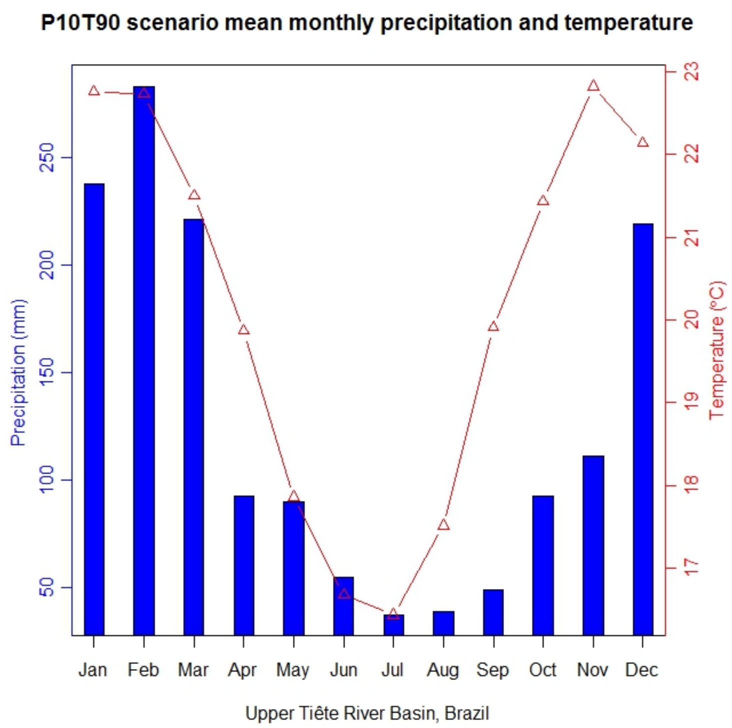


Figure 3. The mean monthly precipitation and temperate in case of the P10T90 scenario for the upper Tiete River basin.

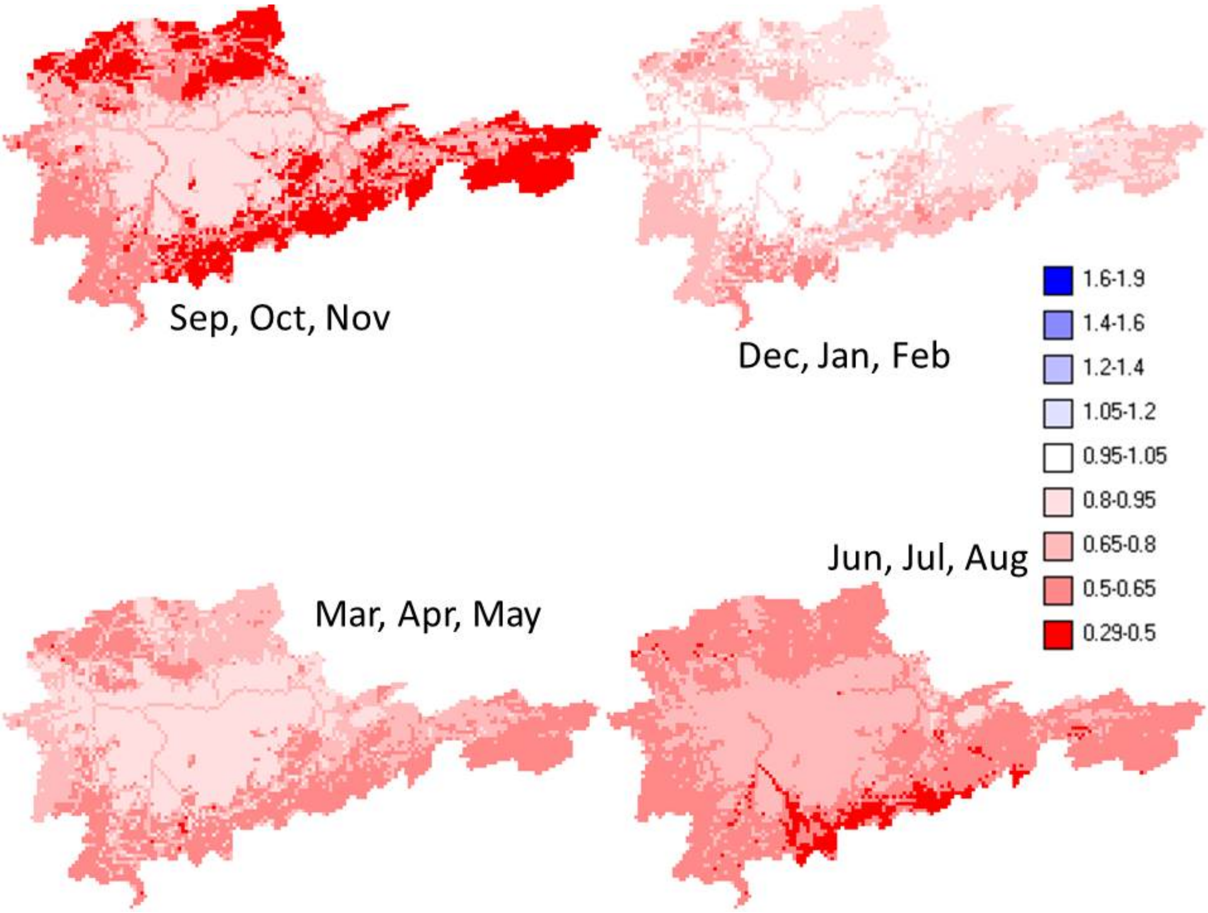


Figure 4. Ratio of P10T90 scenario discharge to baseline discharge (B/A)

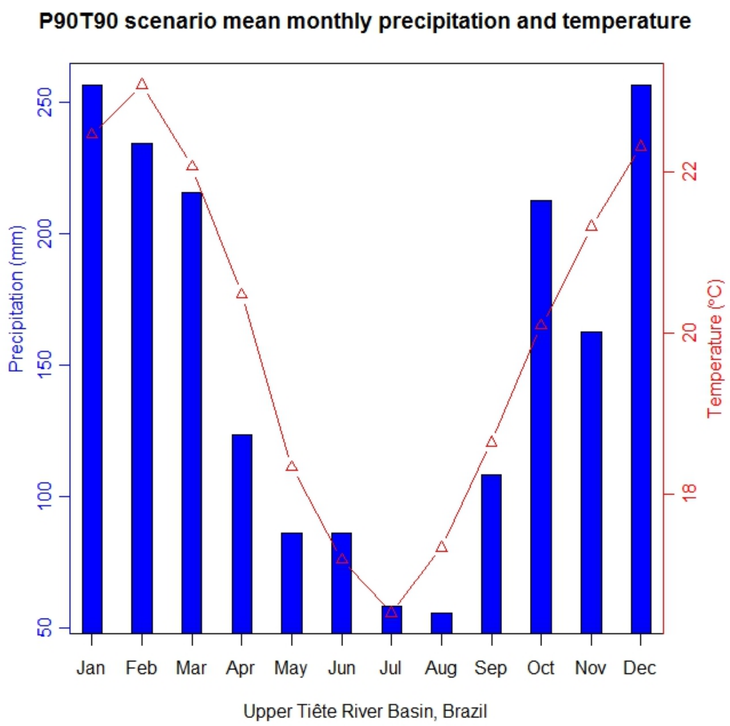


Figure 5. The mean monthly precipitation and temperate in case of the P90T90 scenario for the upper Tiete River basin.

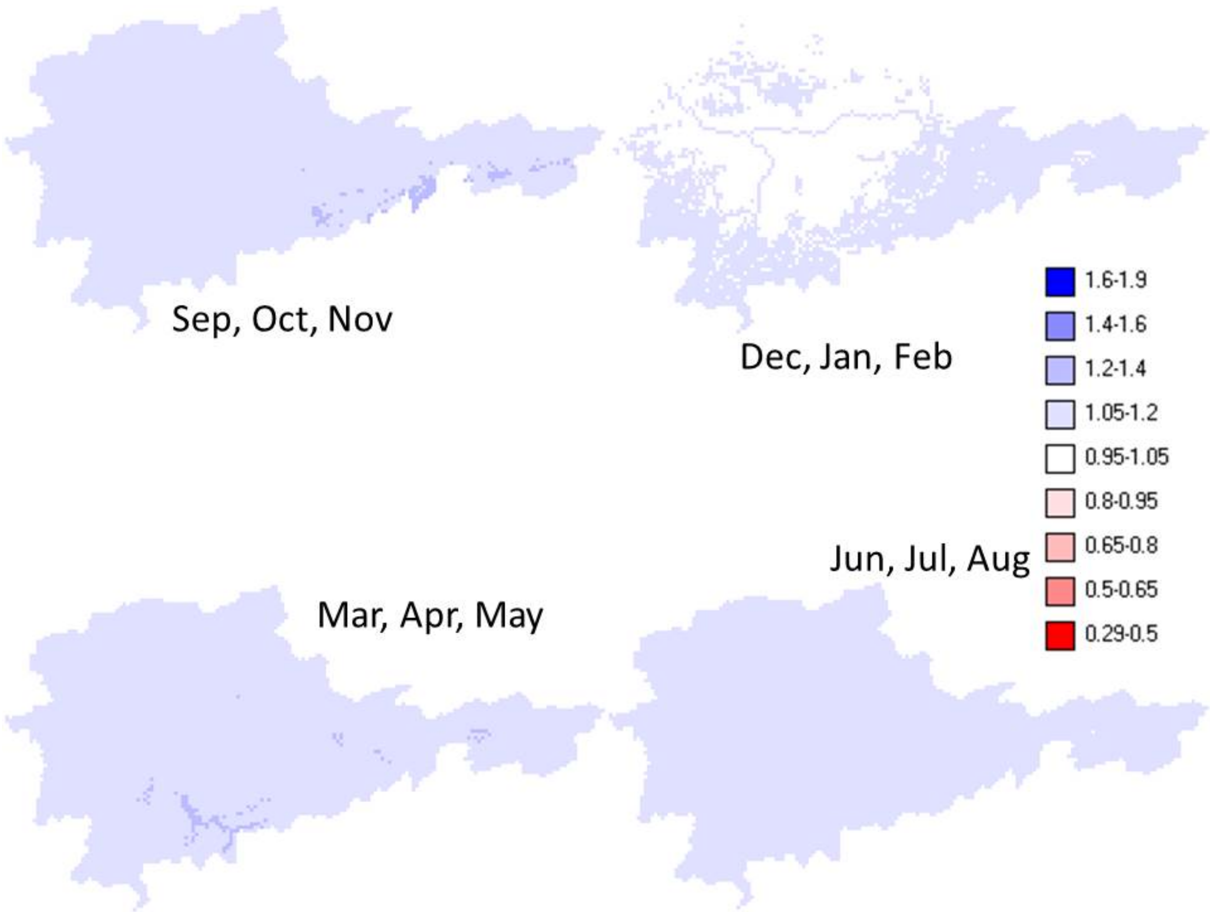


Figure 6. Ratio of P90T90 scenario discharge to baseline discharge (B/A)

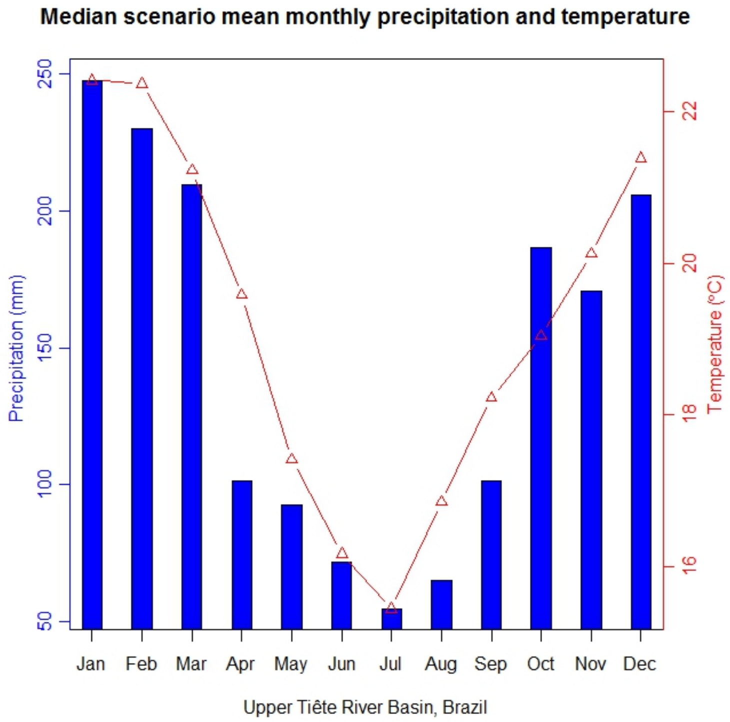


Figure 7. The mean monthly precipitation and temperate in case of the Median scenario for the upper Tiete River basin.

Figure 8. Ratio of Median scenario discharge to baseline discharge (B/A)

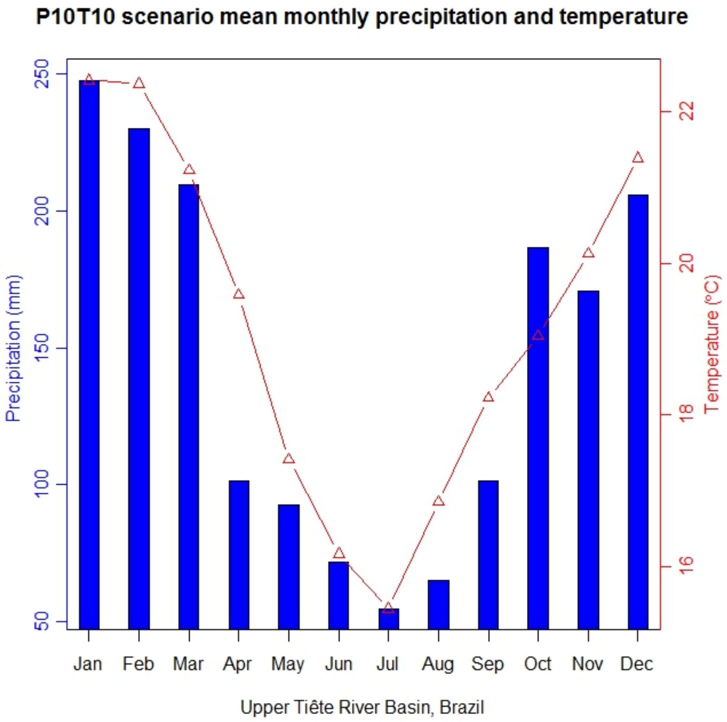


Figure 9. The mean monthly precipitation and temperate in case of the P10T10 scenario for the upper Tiete River basin.

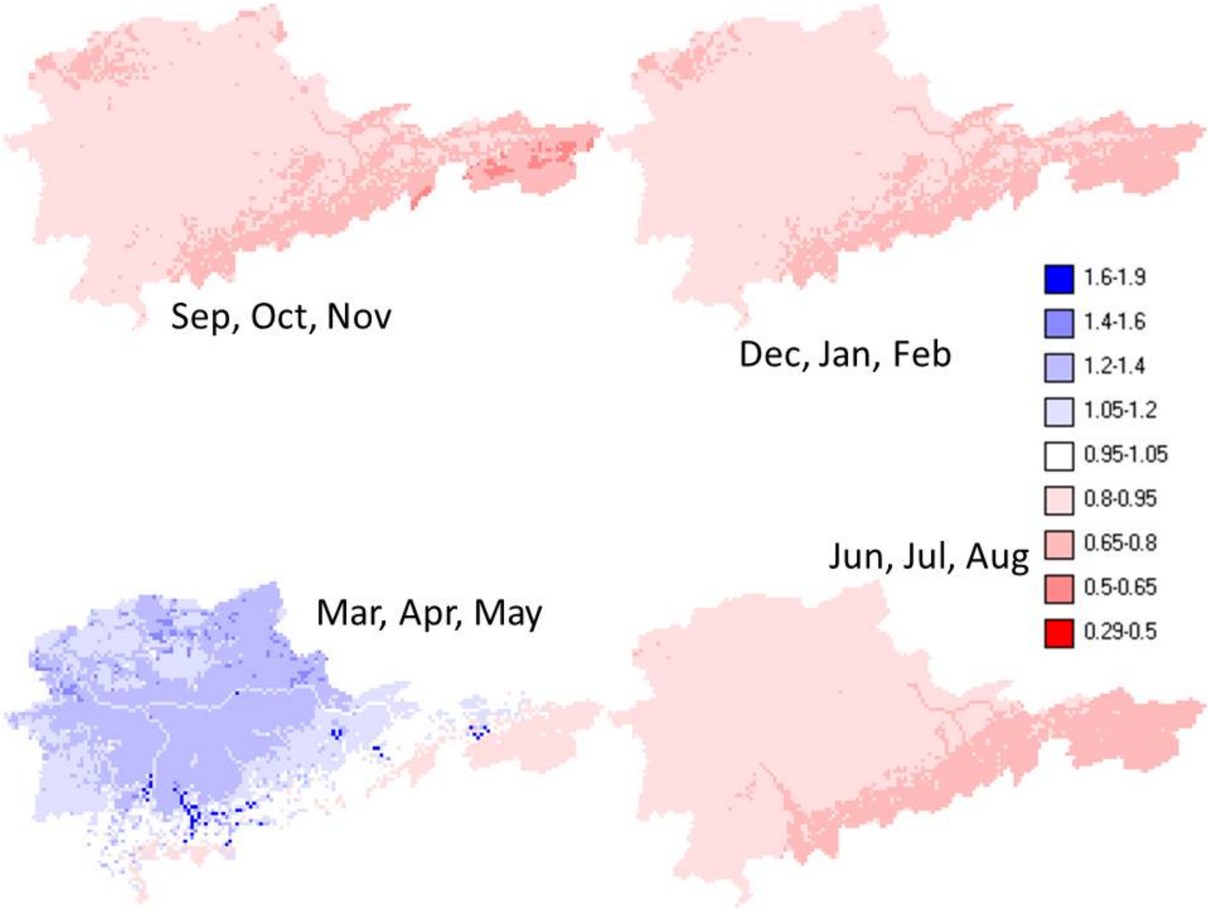


Figure 10. Ratio of P10T10 scenario discharge to baseline discharge (B/A)

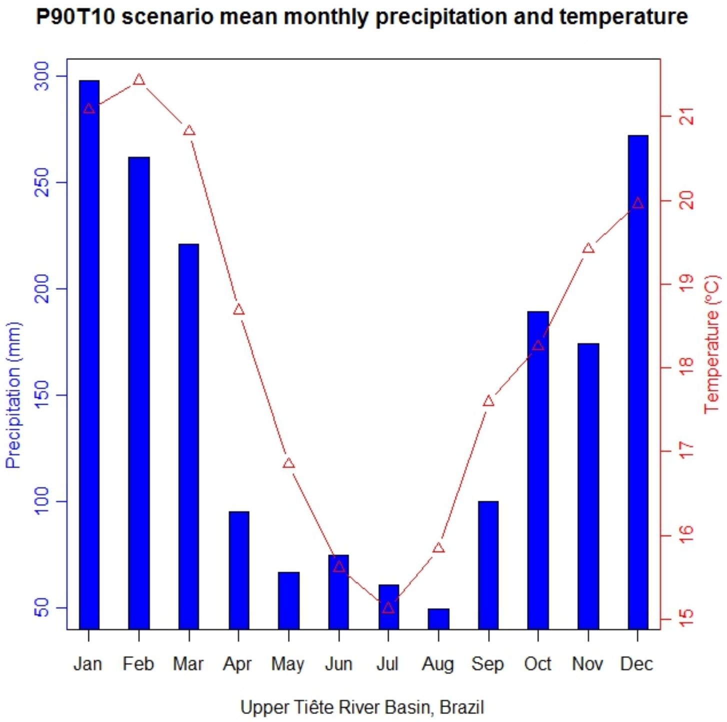


Figure 11. The mean monthly precipitation and temperate in case of the P90T10 scenario for the upper Tiete River basin.

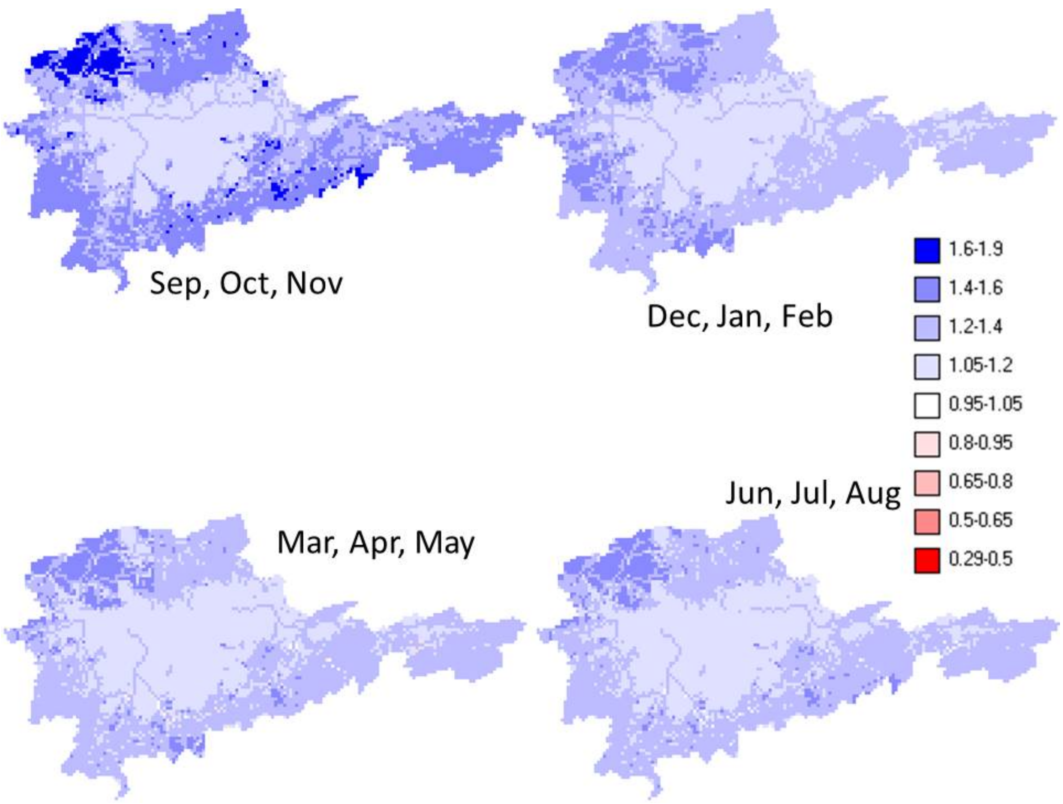


Figure 12. Ratio of P90T10 scenario discharge to baseline discharge (B/A)

Table 1. Means of the ratios for the 5 future scenarios for the upper Tiete River basin.

B/A average	P10T90	P90T90	M	P10T10	P90T10	mean
Sep, Oct, Nov	0.626	1.143	0.98	0.841	1.347	0.987
Dec, Jan, Feb	0.859	1.056	0.973	0.843	1.275	1.001
Mar, Apr, May	0.729	1.134	0.995	1.149	1.248	1.051
Jun, Jul, Aug	0.635	1.103	0.993	0.847	1.253	0.966
mean	0.712	1.109	0.985	0.920	1.281	

1.4.2 Argentina

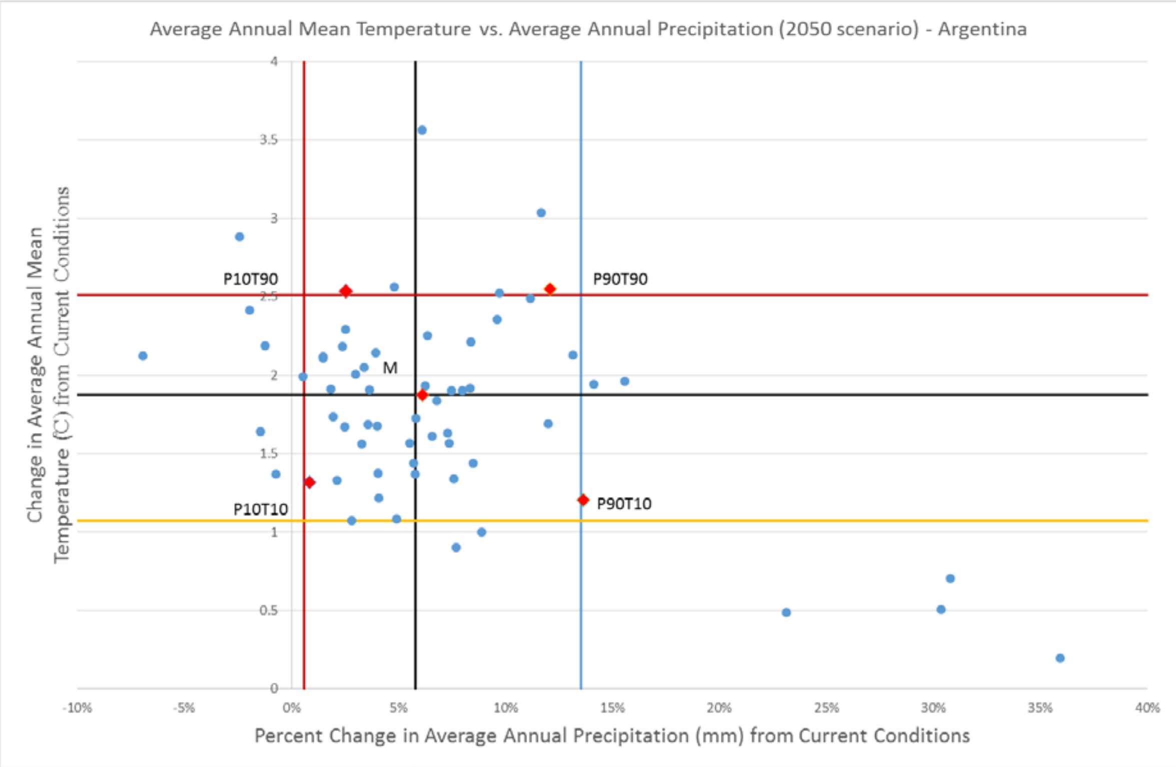


Figure 13. The five future climatic models which were selected from 63 models for Suquía River Basin, Argentina.

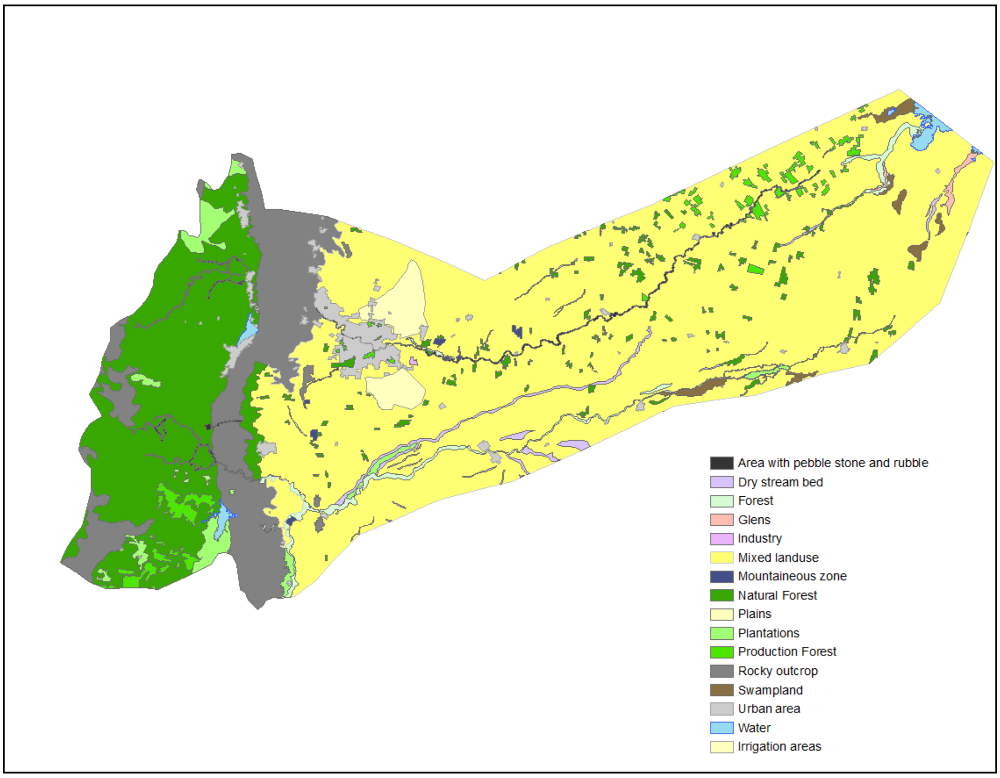


Figure 14. Land use map for Suquía River Basin, Argentina

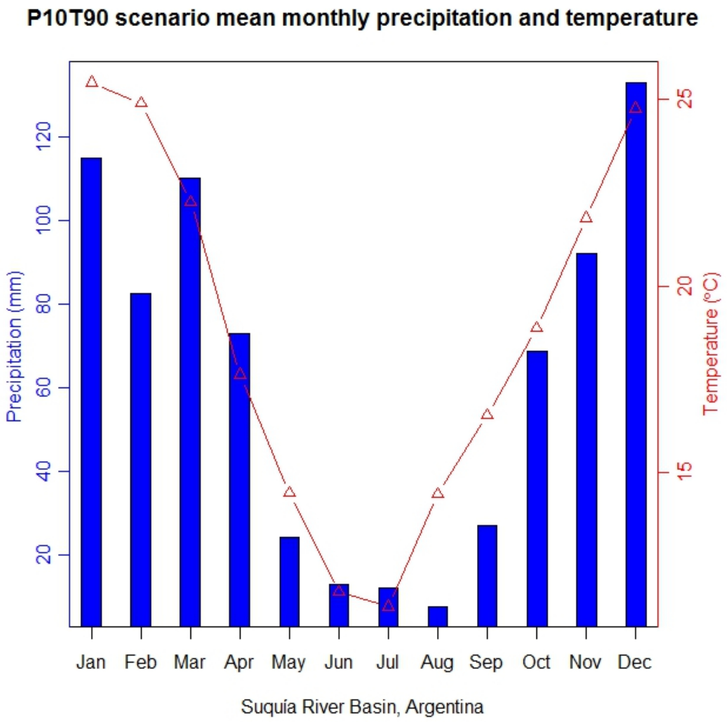


Figure 15. The mean monthly precipitation and temperate in case of the P10T90 scenario for the Suquía River Basin, Argentina.

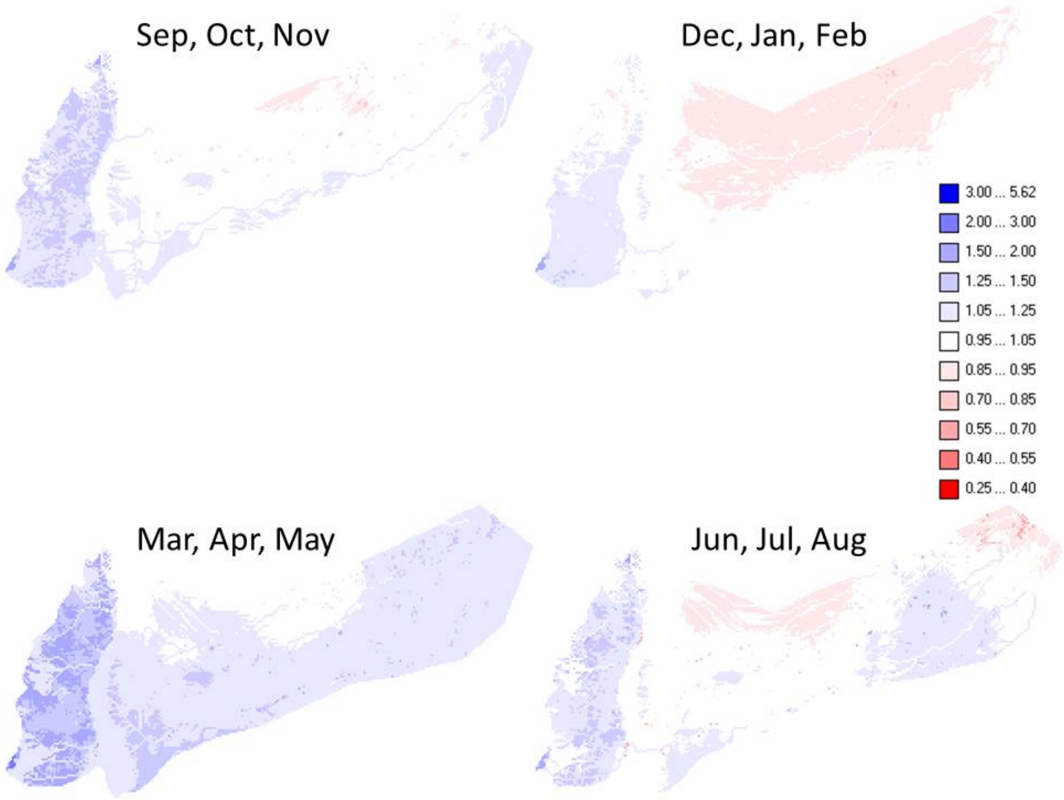


Figure 16. Ratio of P10T90 scenario discharge to baseline discharge (B/A)

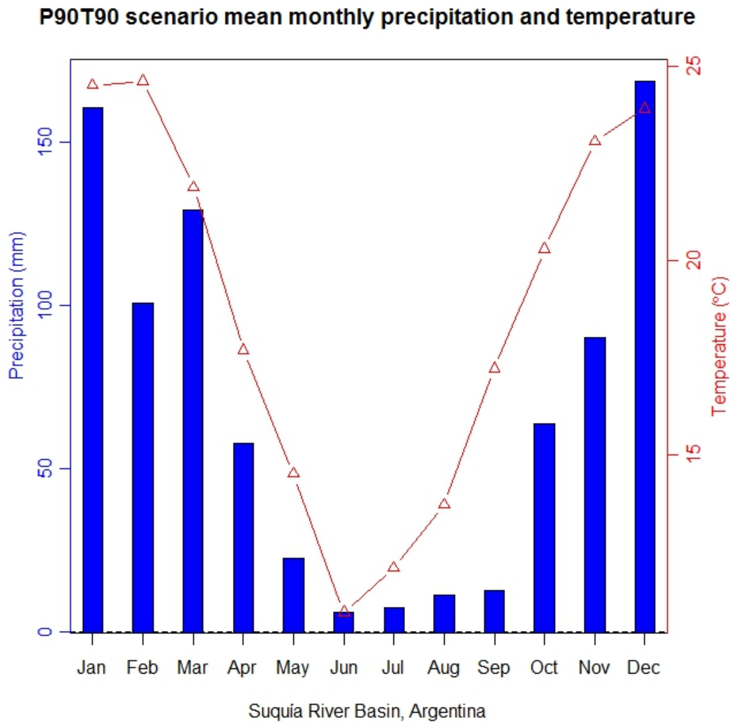


Figure 17. The mean monthly precipitation and temperate in case of the P90T10 scenario for the Suquía River Basin, Argentina.

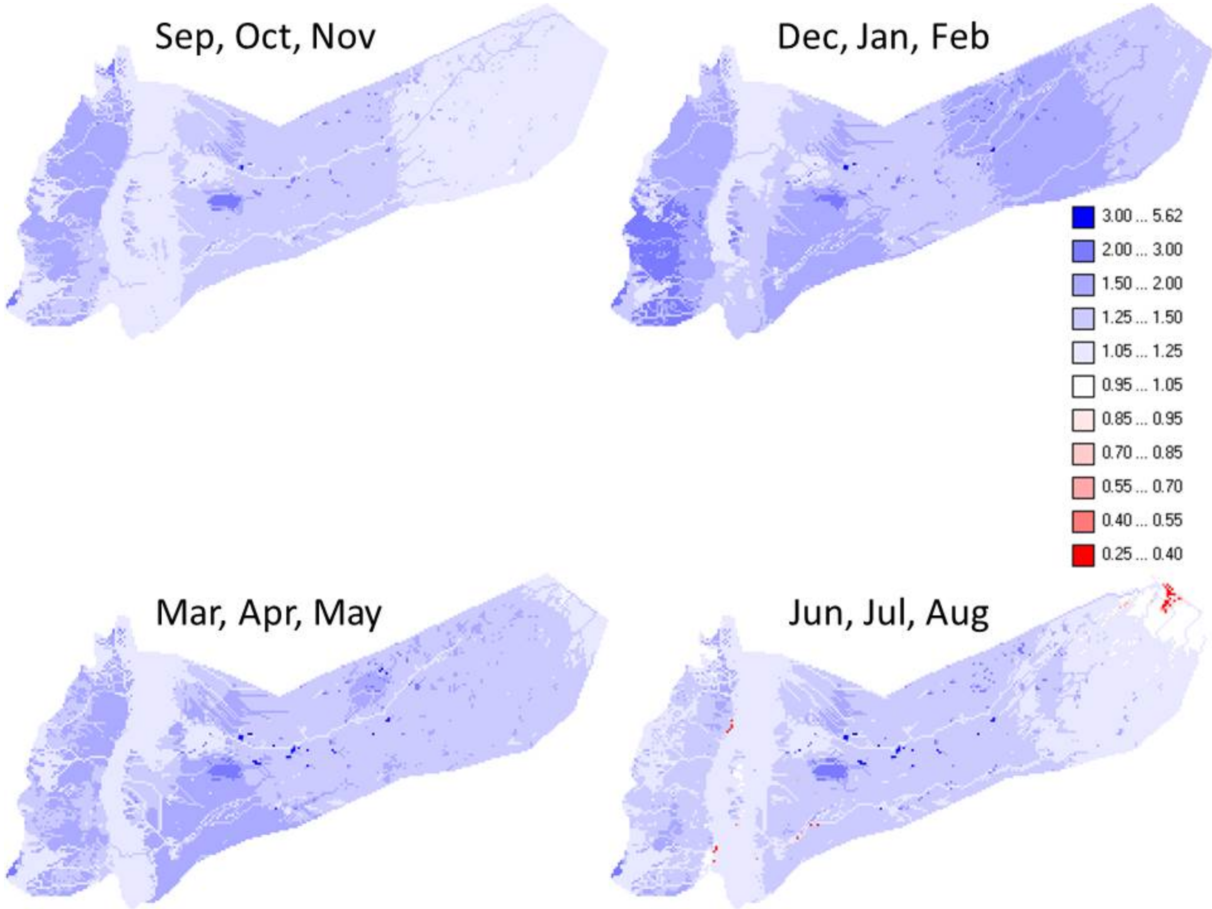


Figure 18. Ratio of P90T90 scenario discharge to baseline discharge (B/A)

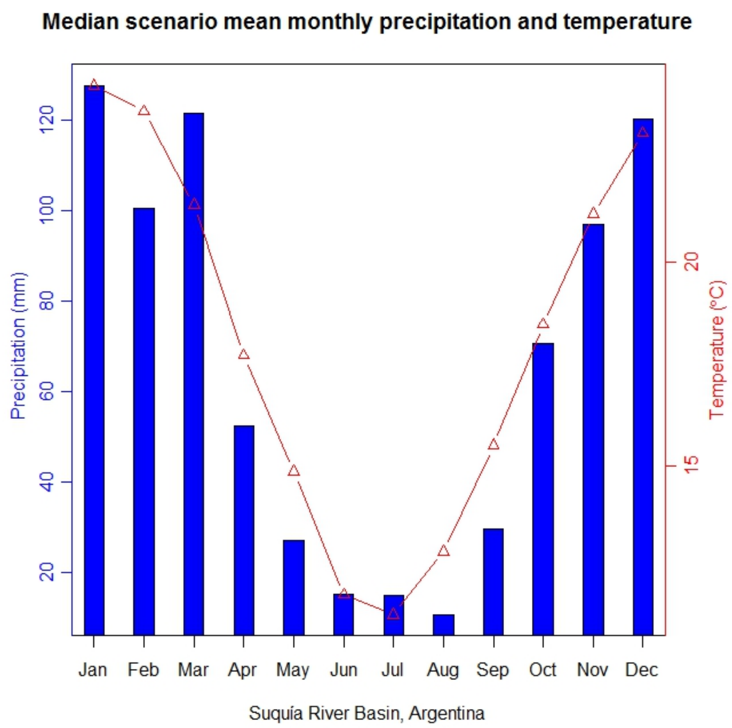


Figure 19. The mean monthly precipitation and temperate in case of the Median scenario for the Suquía River Basin, Argentina.

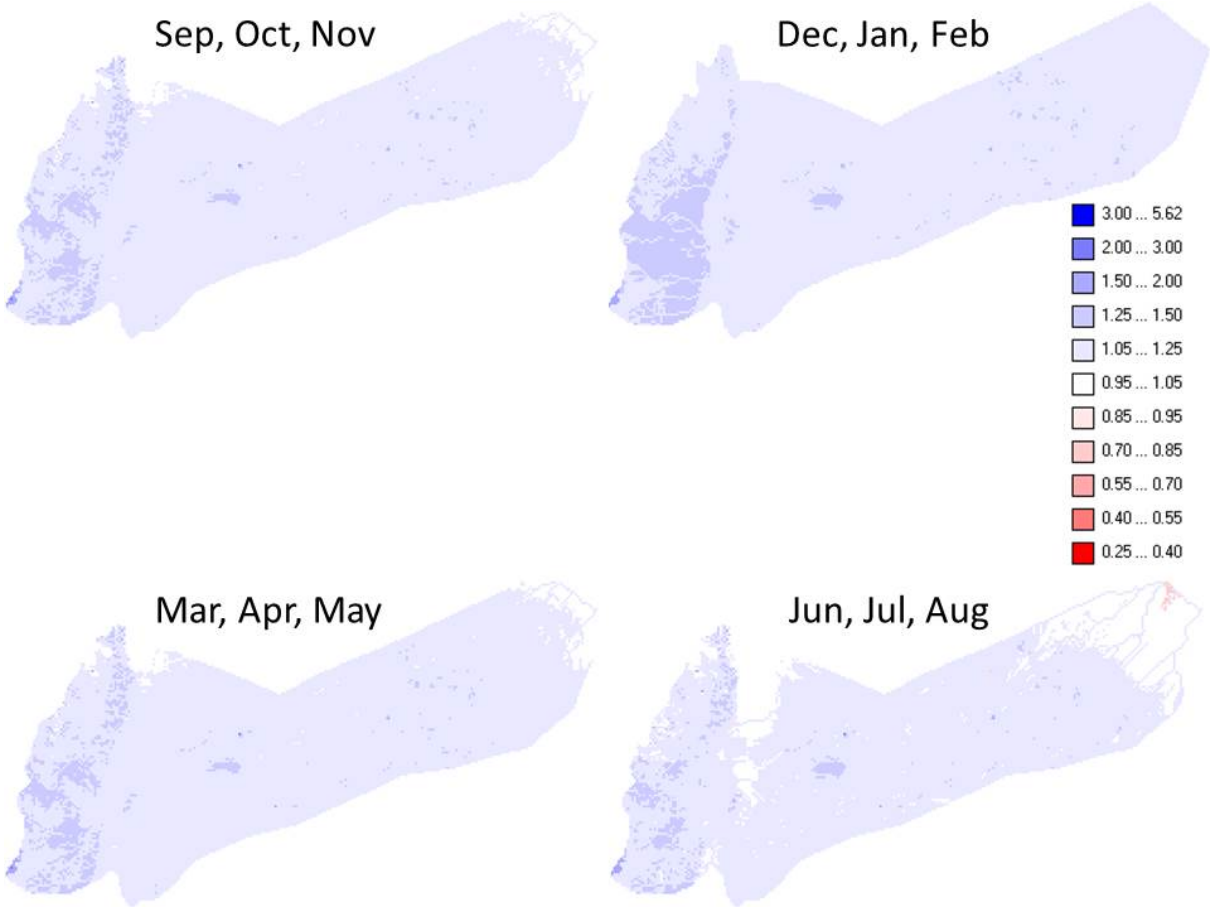


Figure 20. Ratio of Median scenario discharge to baseline discharge (B/A)

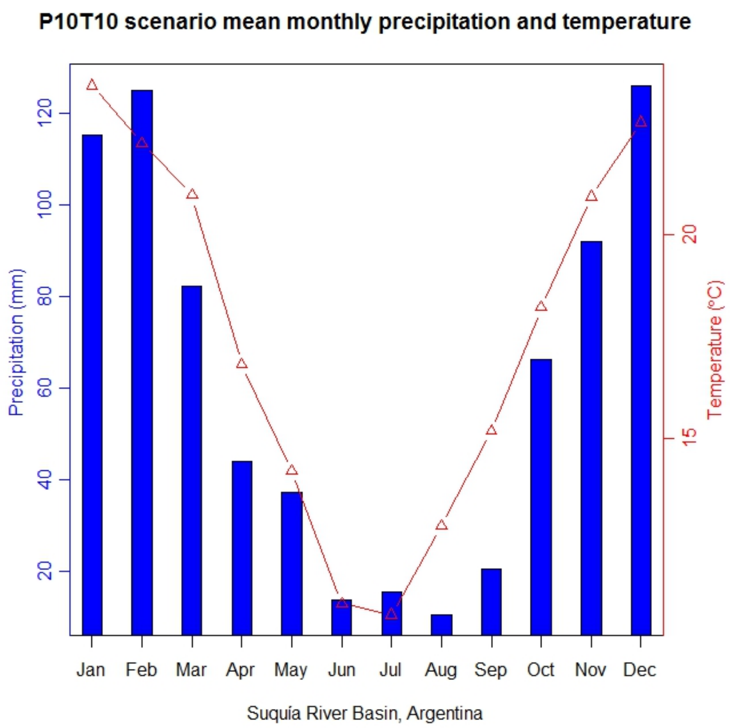


Figure 21. The mean monthly precipitation and temperate in case of the P10T10 scenario for the Suquía River Basin, Argentina.

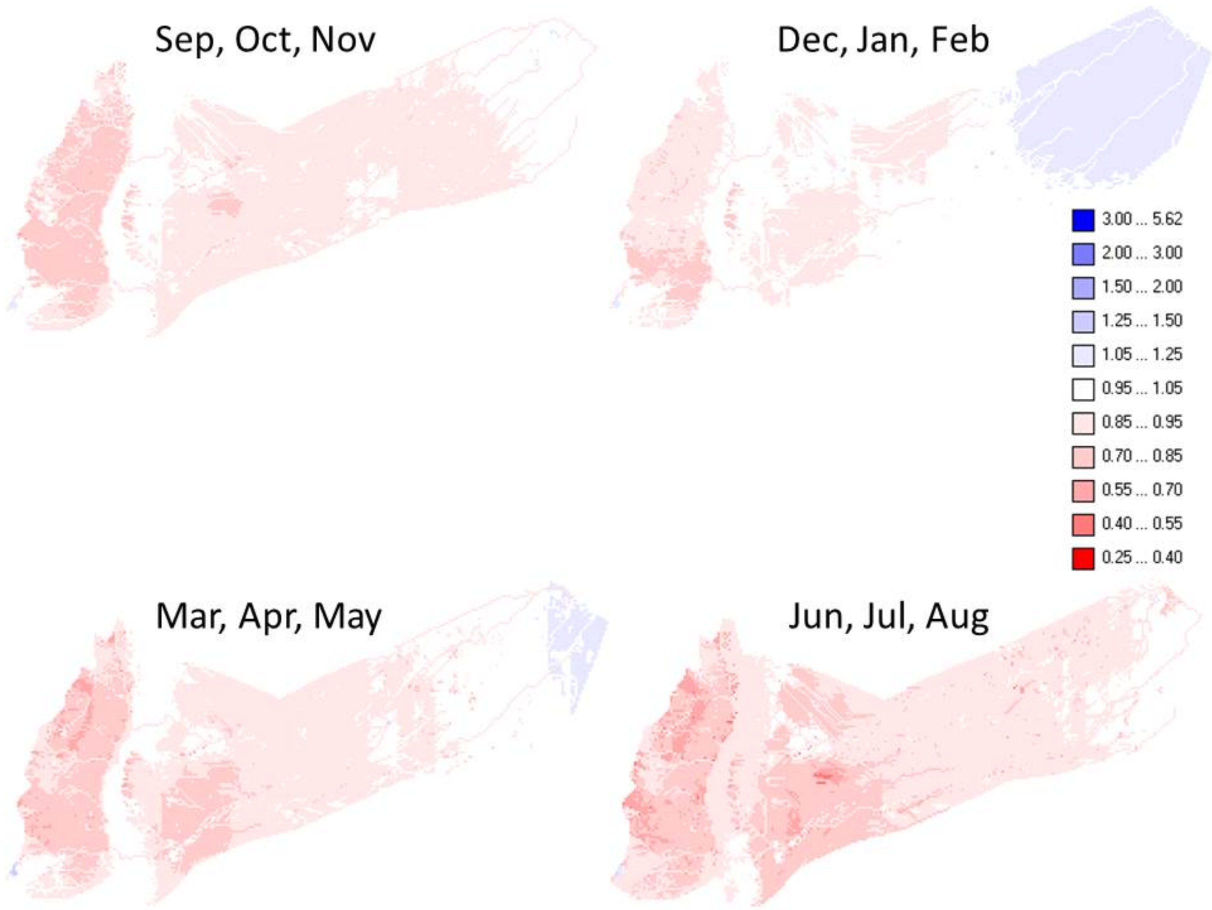


Figure 22. Ratio of P10T10 scenario discharge to baseline discharge (B/A)

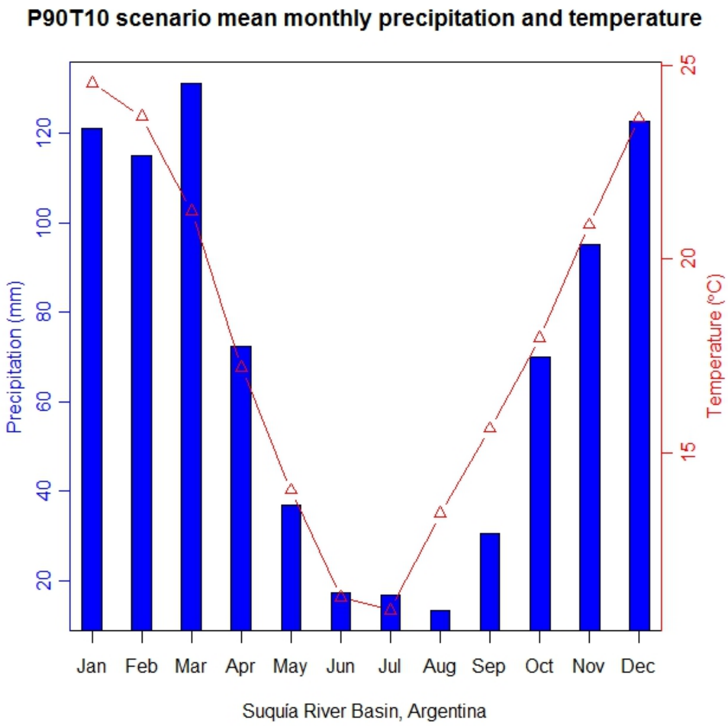


Figure 23. The mean monthly precipitation and temperate in case of the P90T10 scenario for the Suquía River Basin, Argentina.

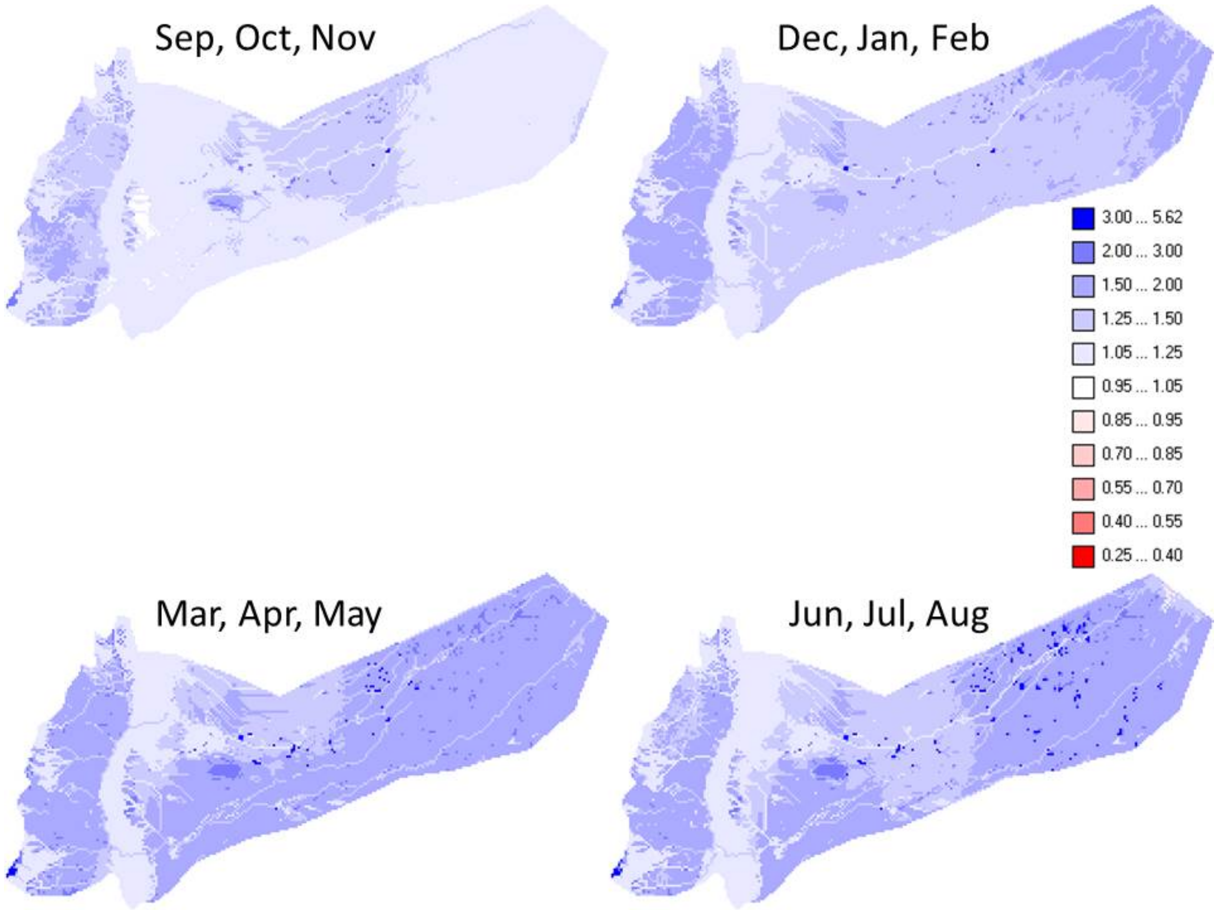


Figure 24. Ratio of P90T10 scenario discharge to baseline discharge (B/A)

Table 2. Average basin values of the ratios of future scenario discharge to baseline discharge (B/A) for the 5 future scenarios

B/A average	P10T90	P90T90	M	P10T10	P90T10	mean
Sep, Oct, Nov	1.056	1.303	1.046	0.924	1.231	1.112
Dec, Jan, Feb	0.984	1.513	1.158	0.982	1.422	1.212
Mar, Apr, May	1.181	1.416	1.12	0.918	1.575	1.242
Jun, Jul, Aug	1.04	1.276	1.095	0.874	1.551	1.167
mean	1.065	1.377	1.105	0.925	1.445	

1.4.3 Chile

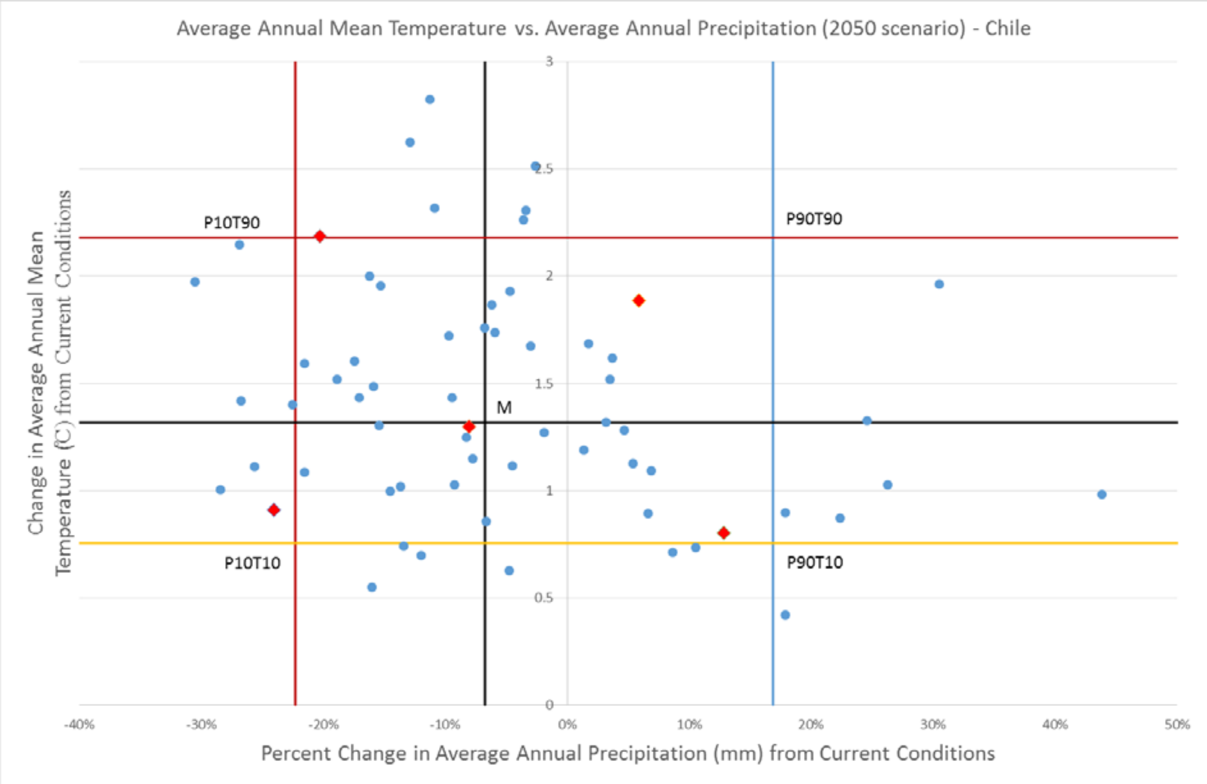


Figure 25. Five future climatic models were selected from 63 climatic models for Copiapó River Basin, Chile

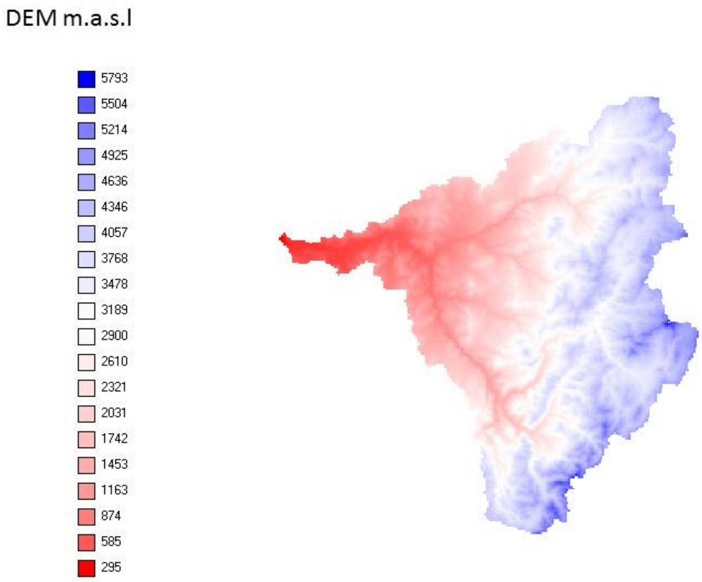


Figure 26. Altitude map of the Copiapó river basin.

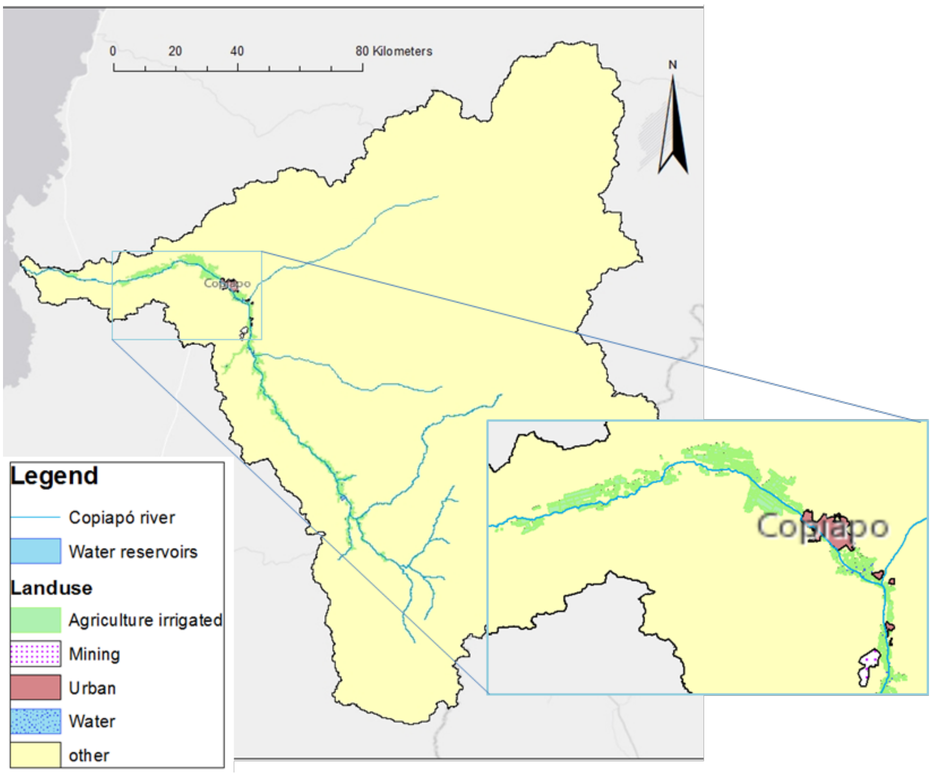


Figure 27. Land use in the Copiapó river basin.

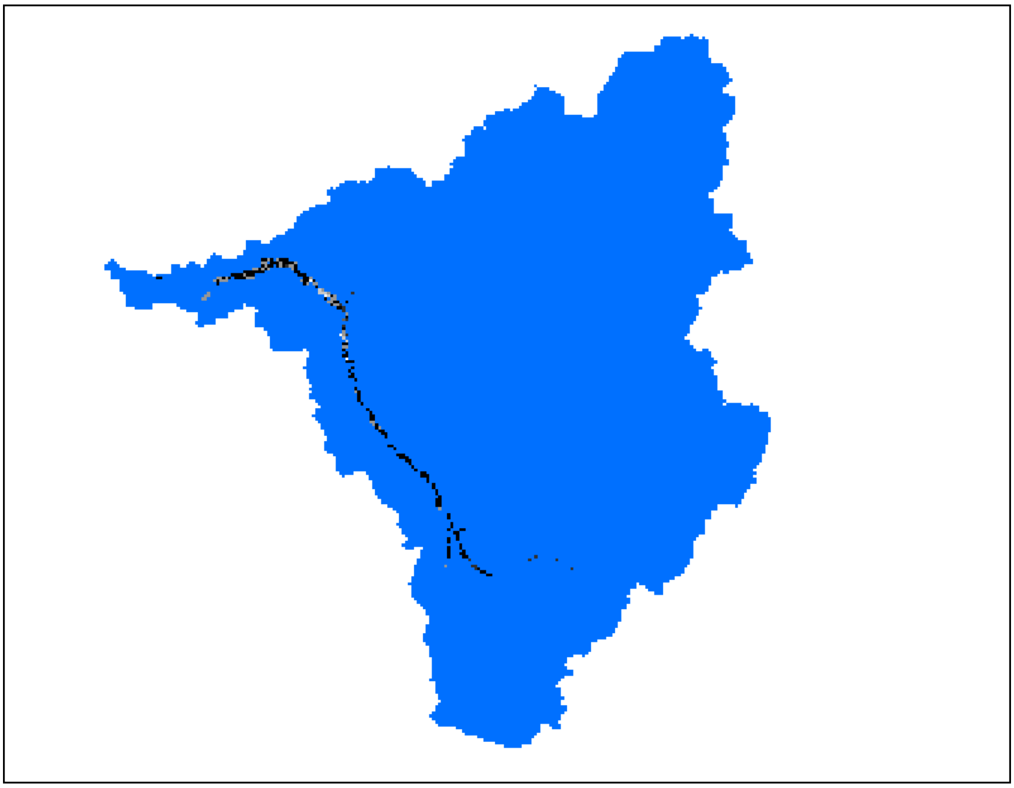


Figure 28. Map of water abstraction points (black, grey and white points) in the Copiapó river basin.

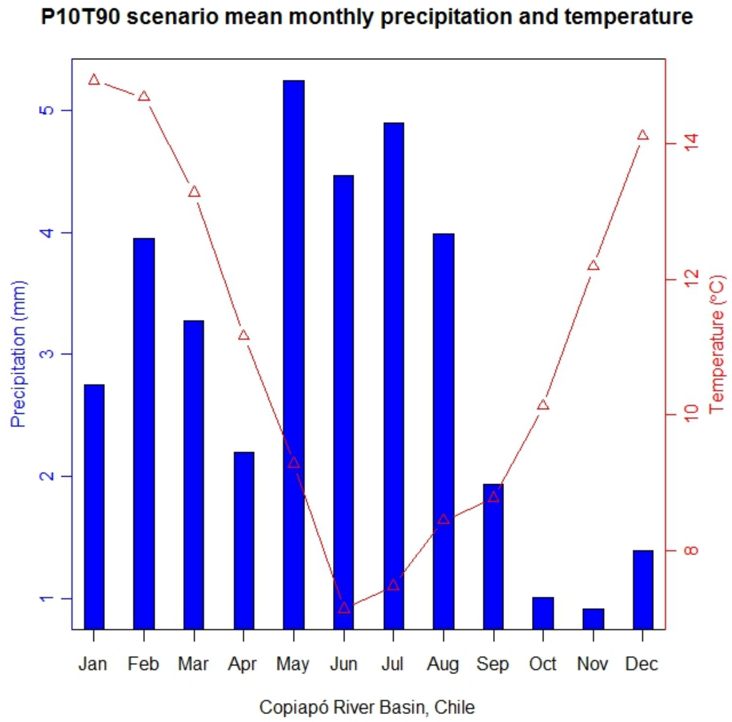


Figure 29. The mean monthly precipitation and temperate in case of the P10T90 scenario for the Copiapó river basin.

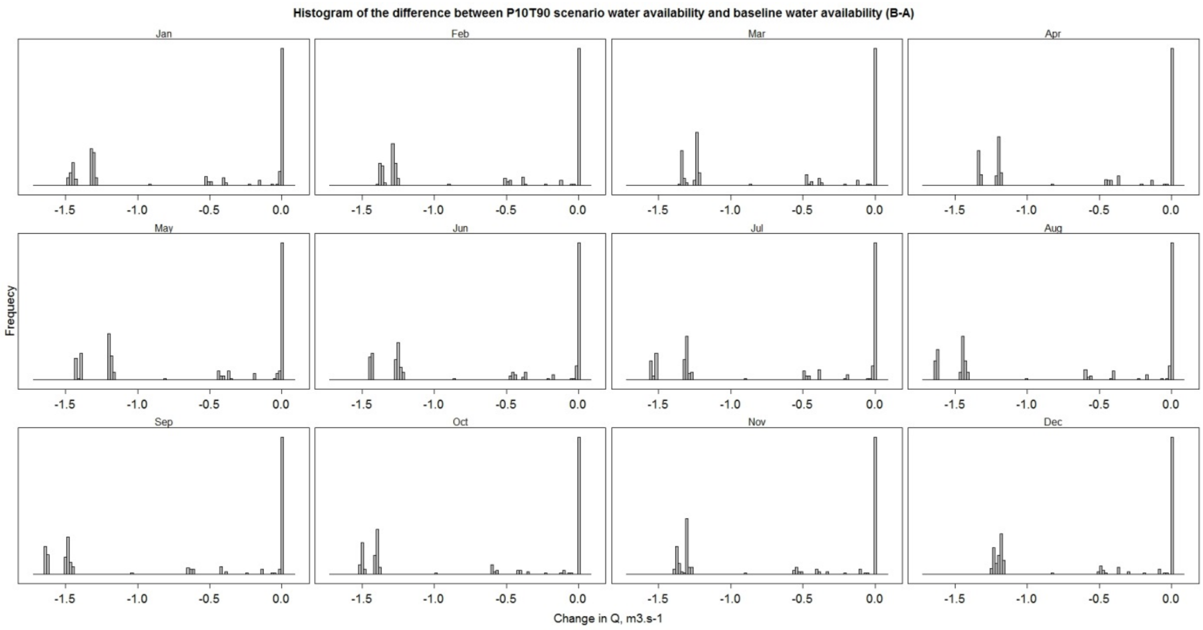


Figure 30. Histogram of the difference between P10T90 scenario water availability and baseline water availability (B-A) at the water abstraction points.

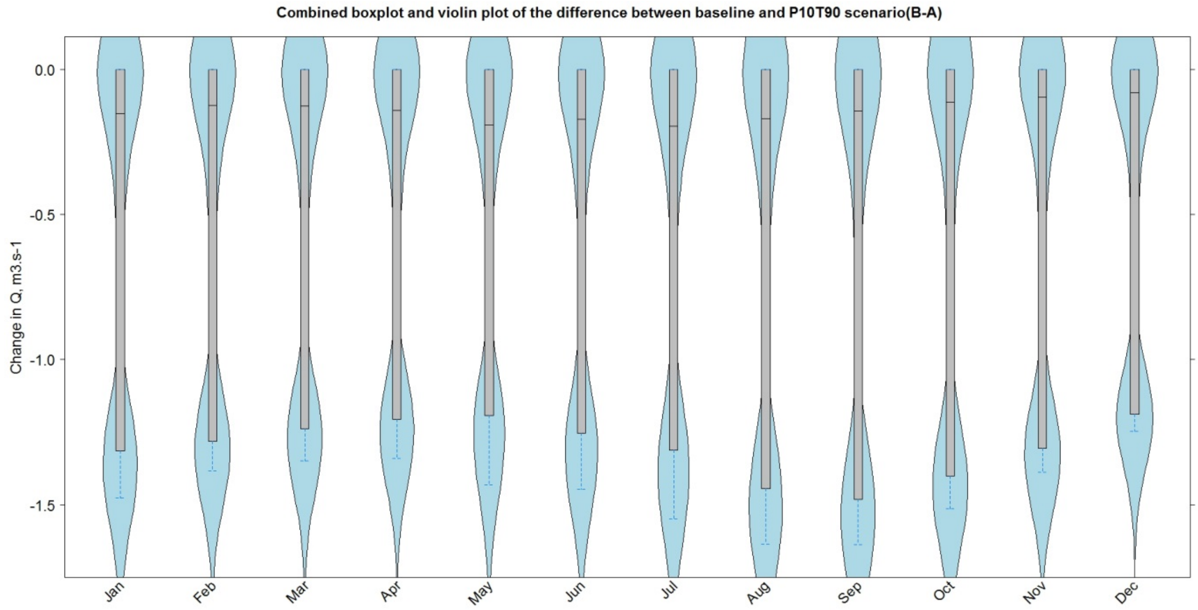


Figure 31. Combined boxplot and violin plot of the difference between P10T90 scenario water availability and baseline water availability (B-A) at the water abstraction points.

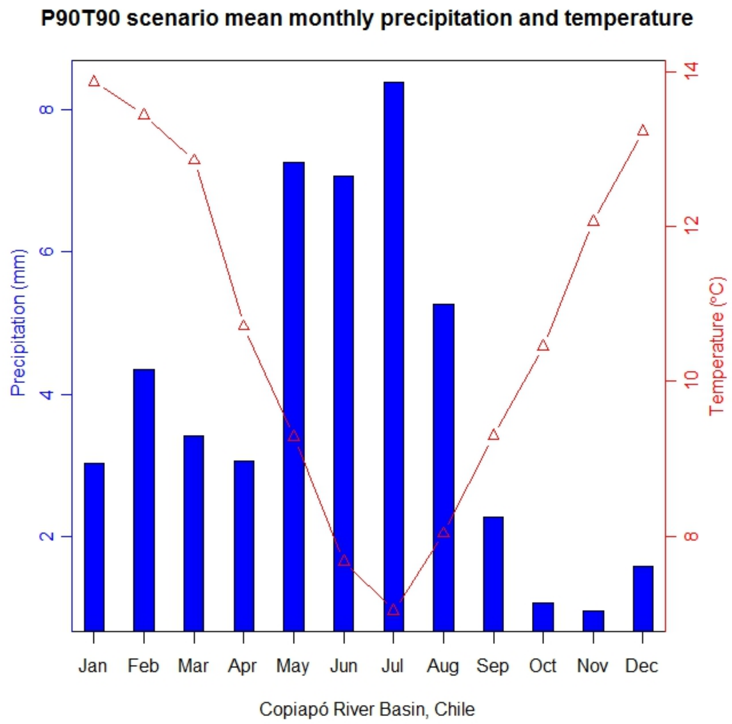


Figure 32. The mean monthly precipitation and temperate in case of the P90T90 scenario for the Copiapó river basin.

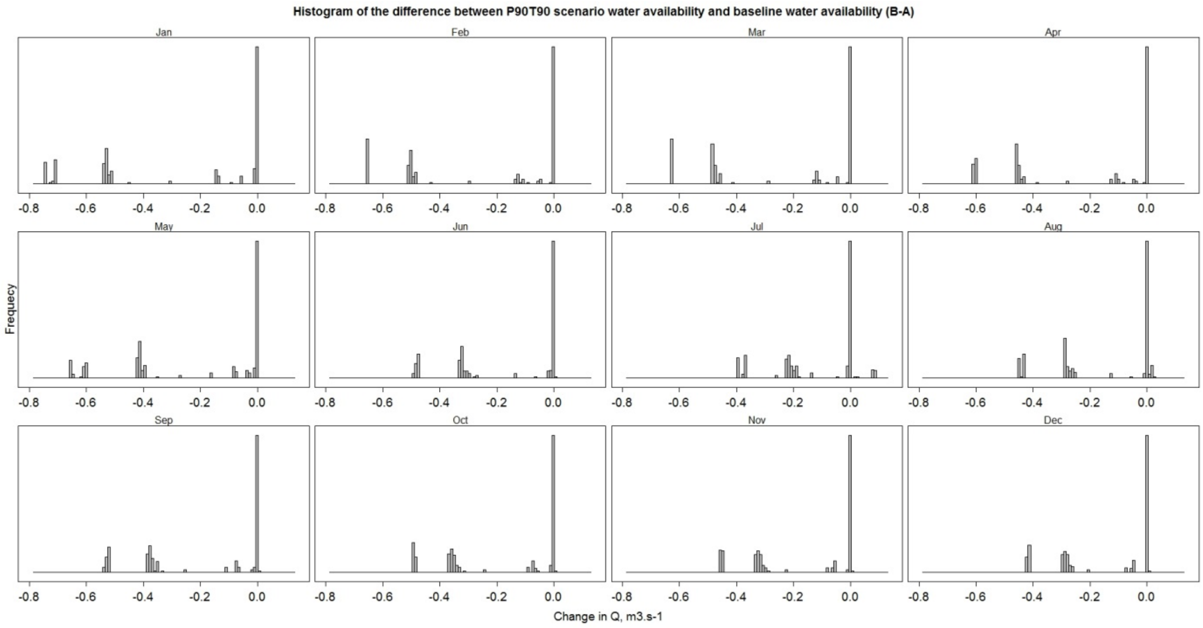


Figure 33. Histogram of the difference between P90T90 scenario water availability and baseline water availability (B-A) at the water abstraction points.

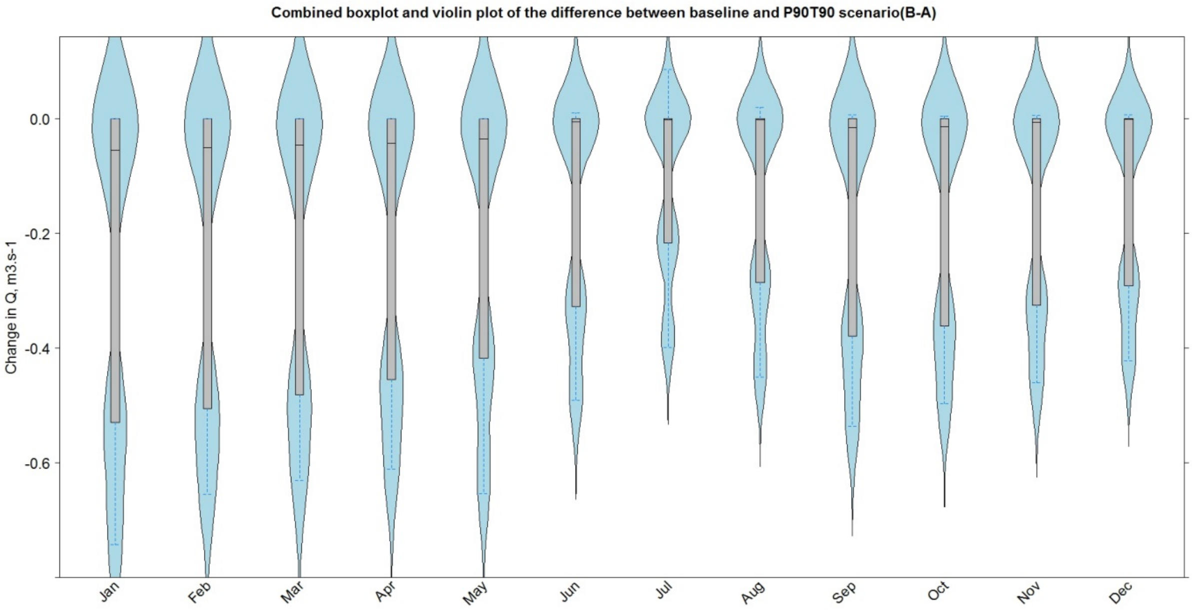


Figure 34. Combined boxplot and violin plot of the difference between P90T90 scenario water availability and baseline water availability (B-A) at the water abstraction points.

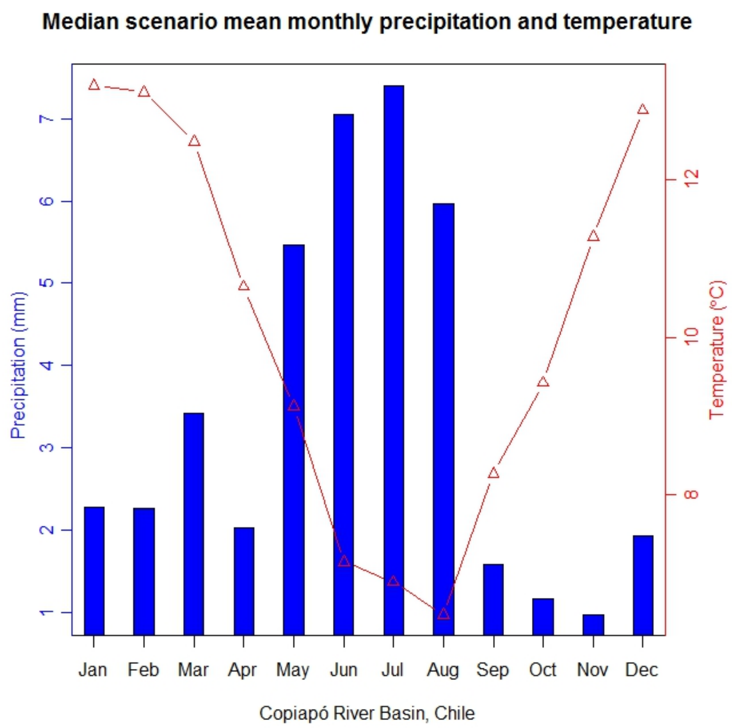


Figure 35. The mean monthly precipitation and temperate in case of the Median scenario for the Copiapó river basin.

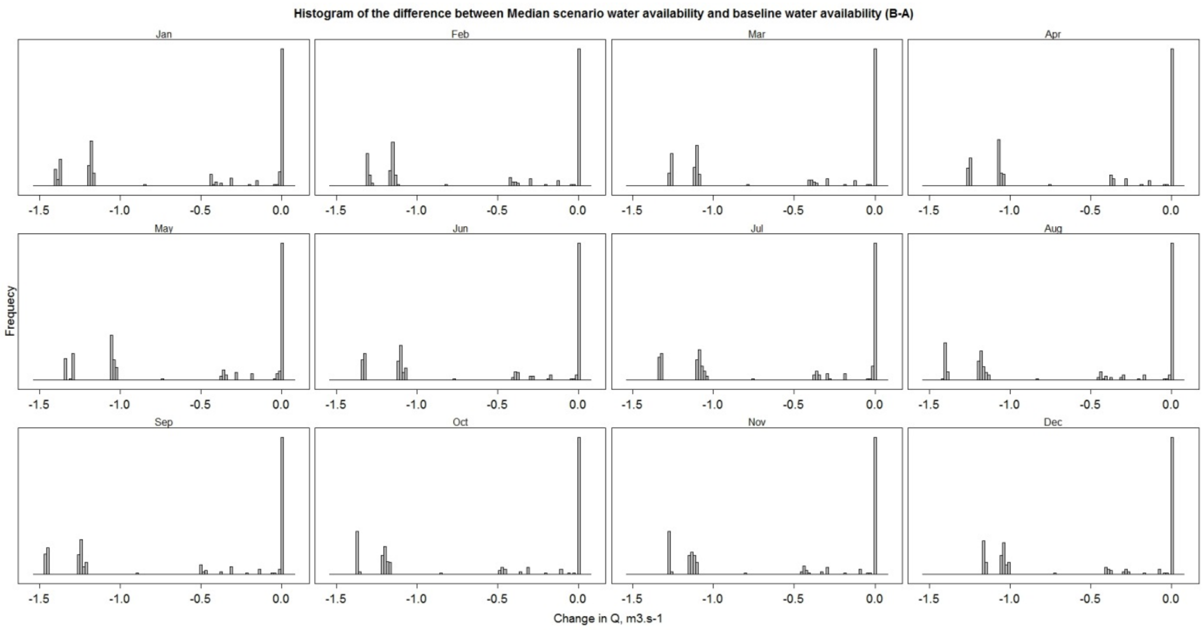


Figure 36. Histogram of the difference between Median scenario water availability and baseline water availability (B-A) at the water abstraction points.

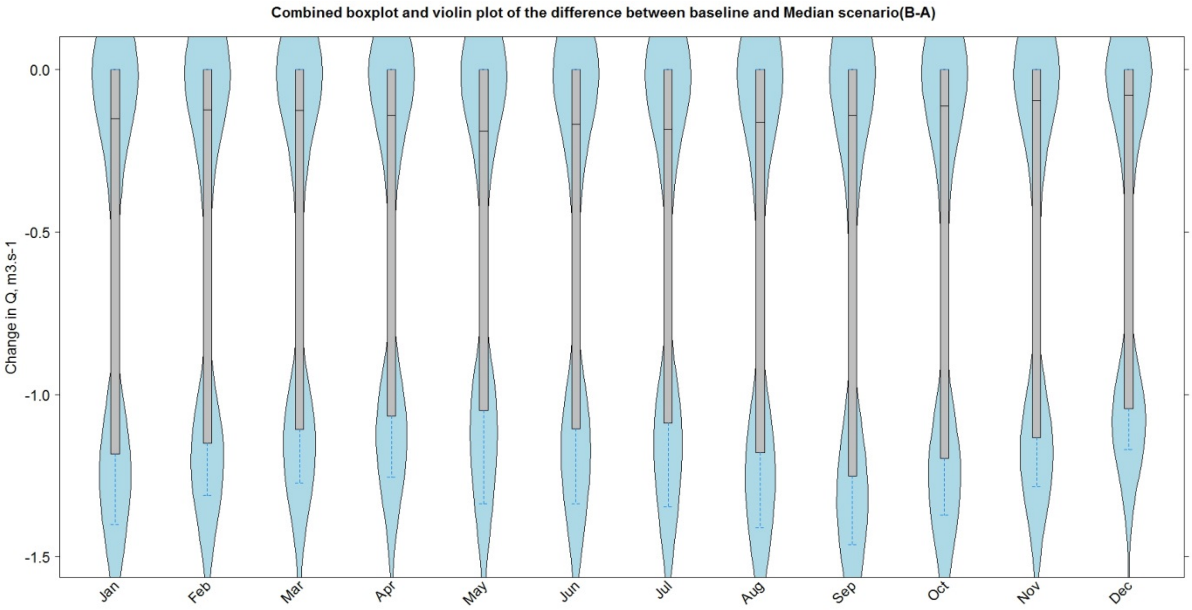


Figure 37. Combined boxplot and violin plot of the difference between Median scenario water availability and baseline water availability (B-A) at the water abstraction points.

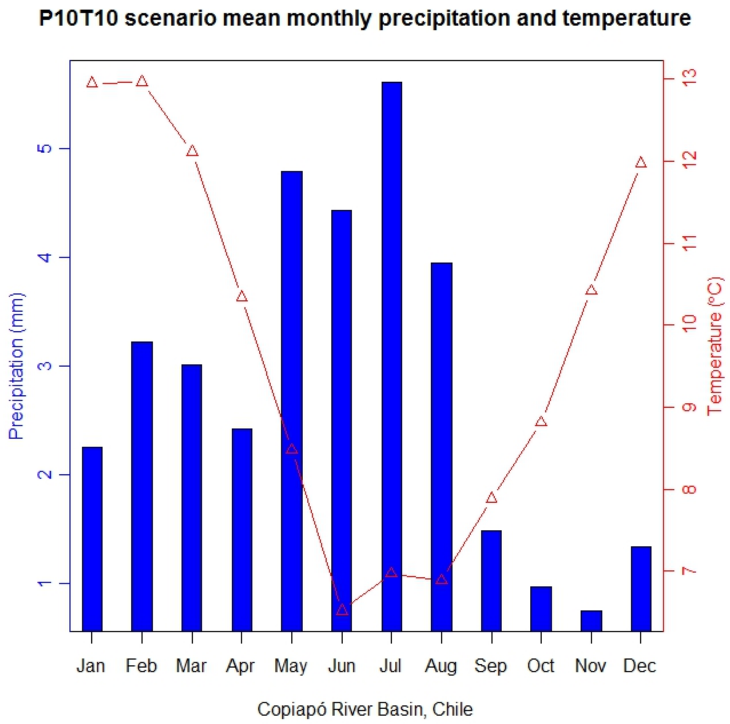


Figure 38. . The mean monthly precipitation and temperate in case of the P10T10 scenario for the Copiapó river basin.

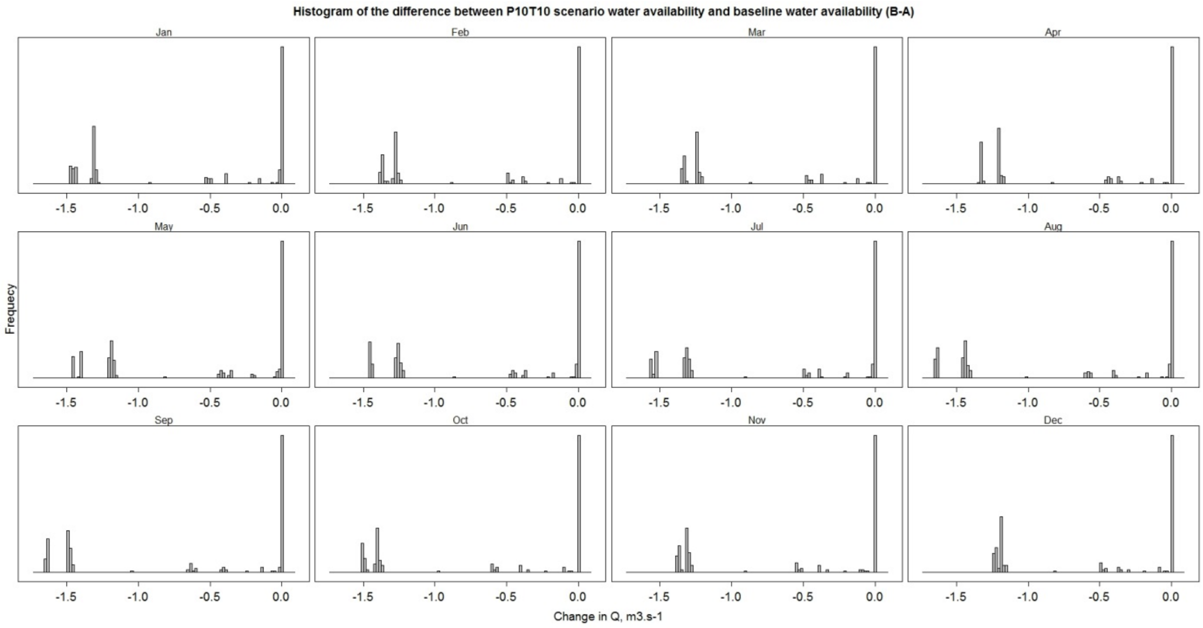


Figure 39. Histogram of the difference between P10T10 scenario water availability and baseline water availability (B-A) at the water abstraction points.

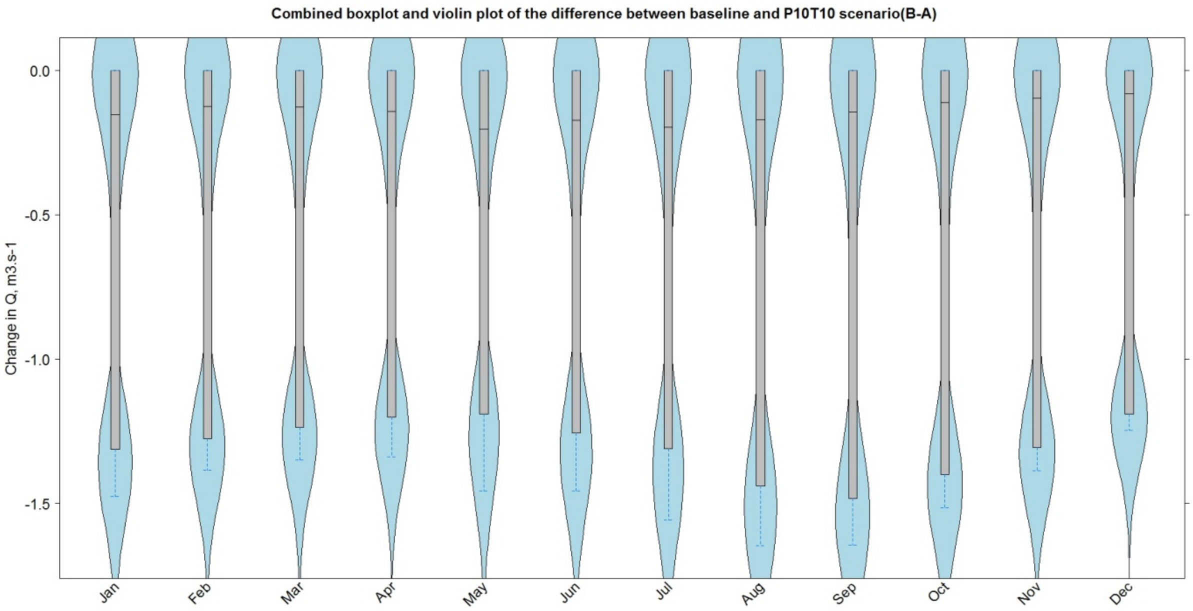


Figure 40. Combined boxplot and violin plot of the difference between P10T10 scenario water availability and baseline water availability (B-A) at the water abstraction points.

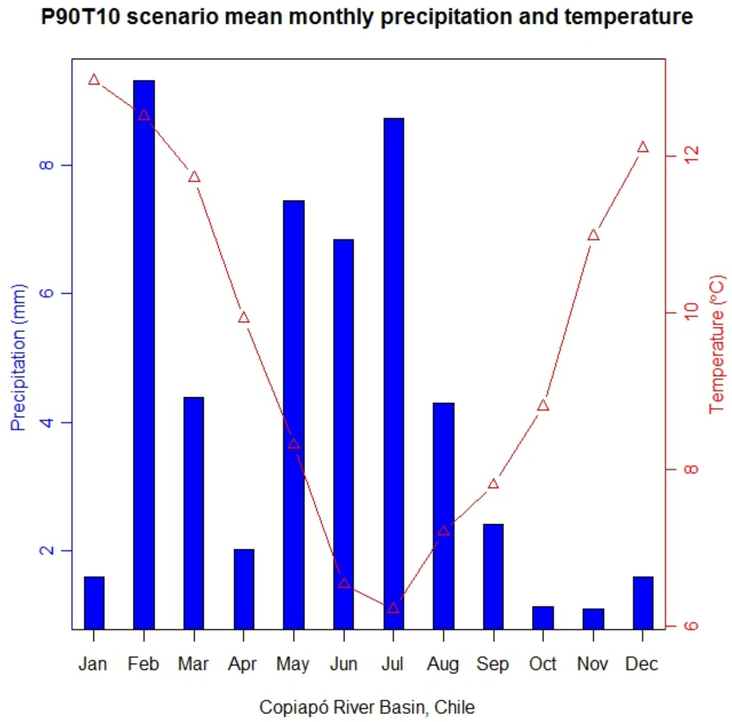


Figure 41 The mean monthly precipitation and temperate in case of the P90T10 scenario for the Copiapó river basin.

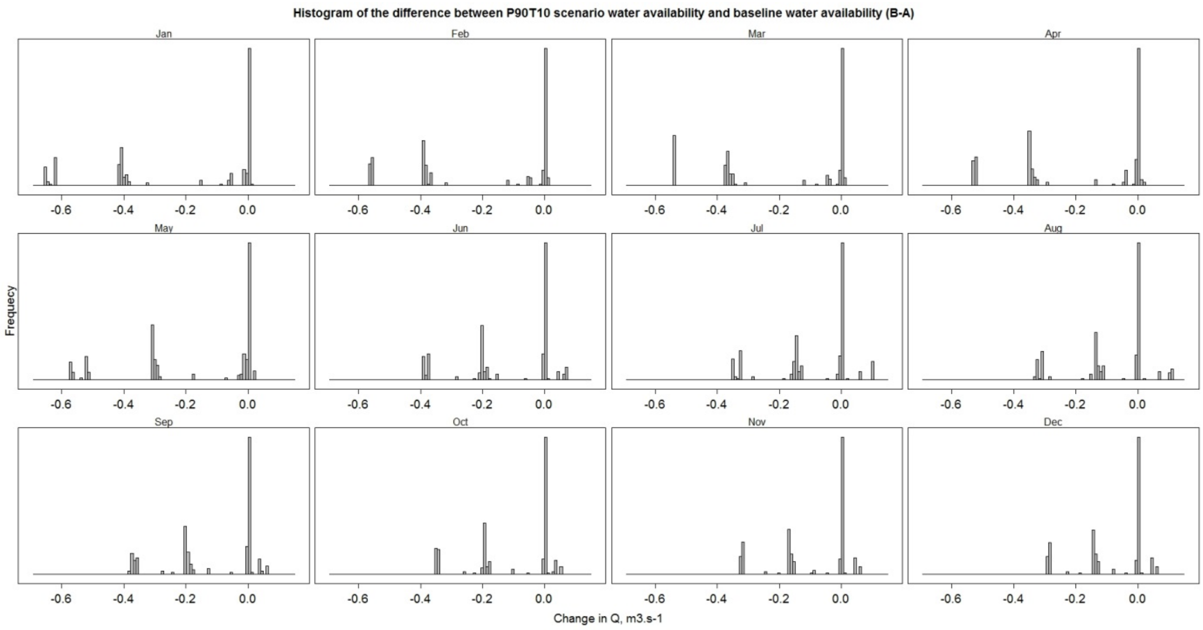


Figure 42. Histogram of the difference between P90T10 scenario water availability and baseline water availability (B-A) at the water abstraction points.

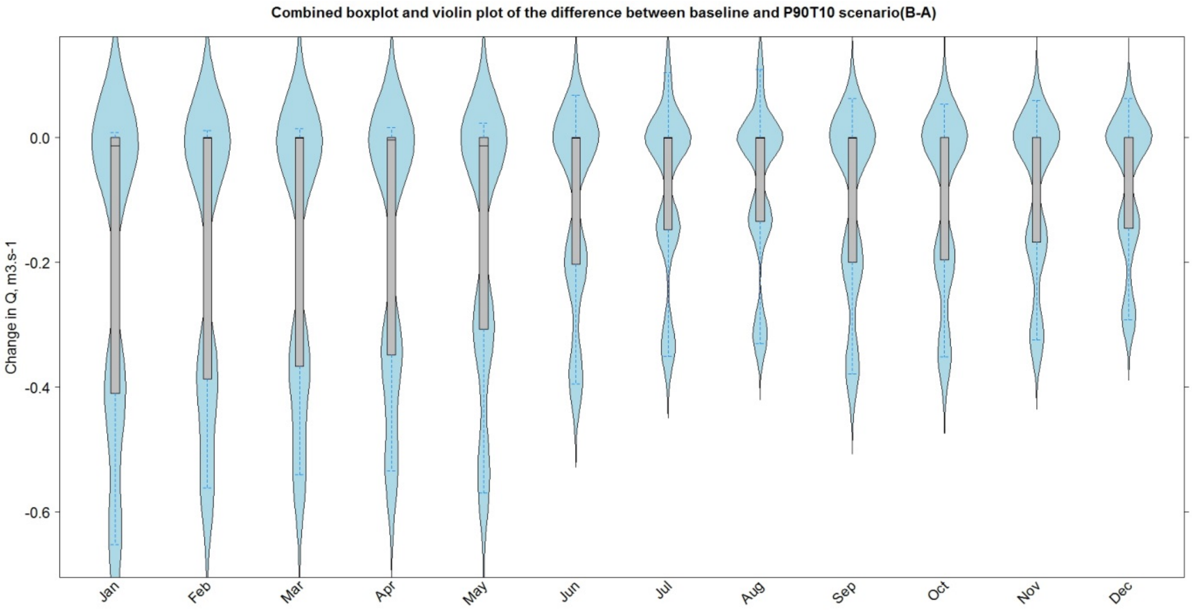


Figure 43. Combined boxplot and violin plot of the difference between P90T10 scenario water availability and baseline water availability (B-A) at the water abstraction points.

Table 3. Monthly average values of the difference between future scenario discharge to baseline discharge (B-A) for the 5 future scenarios

B-A average	P10T90	P90T90	M	P10T10	P90T10	mean
Jan	-0.60	-0.26	-0.55	-0.60	-0.21	-0.44
Feb	-0.57	-0.24	-0.53	-0.57	-0.19	-0.42
Mar	-0.56	-0.23	-0.51	-0.56	-0.18	-0.41
Apr	-0.55	-0.22	-0.49	-0.55	-0.18	-0.40
May	-0.56	-0.21	-0.50	-0.56	-0.17	-0.40
Jun	-0.58	-0.16	-0.52	-0.58	-0.11	-0.39
Jul	-0.61	-0.11	-0.51	-0.61	-0.09	-0.39
Aug	-0.66	-0.14	-0.55	-0.66	-0.08	-0.42
Sep	-0.67	-0.18	-0.58	-0.68	-0.11	-0.44
Oct	-0.63	-0.17	-0.55	-0.63	-0.10	-0.42
Nov	-0.58	-0.16	-0.52	-0.58	-0.09	-0.39
Dec	-0.53	-0.14	-0.47	-0.53	-0.08	-0.35
mean	-0.60	-0.16	-0.53	-0.60	-0.10	

1.4.4 Mexico

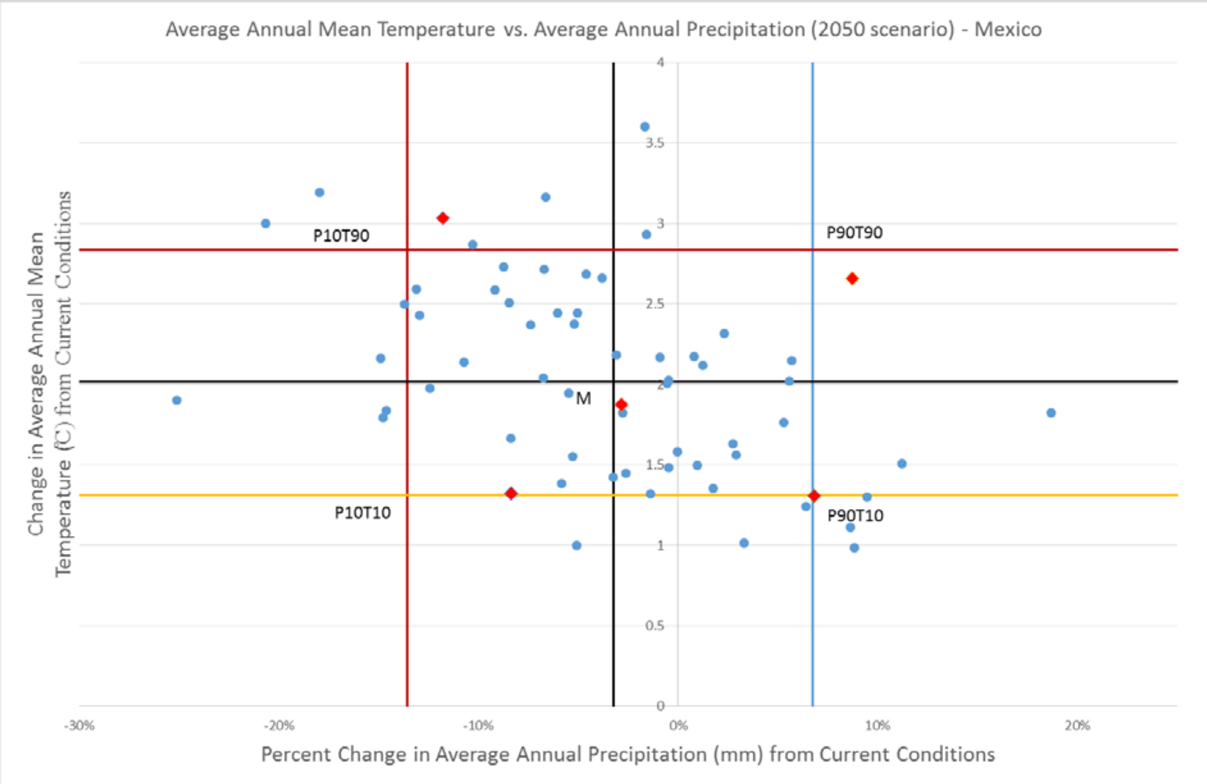


Figure 44. Five future climatic models which were selected from 63 climatic models for Rio Grande/Bravo Lower Basin, Mexico.

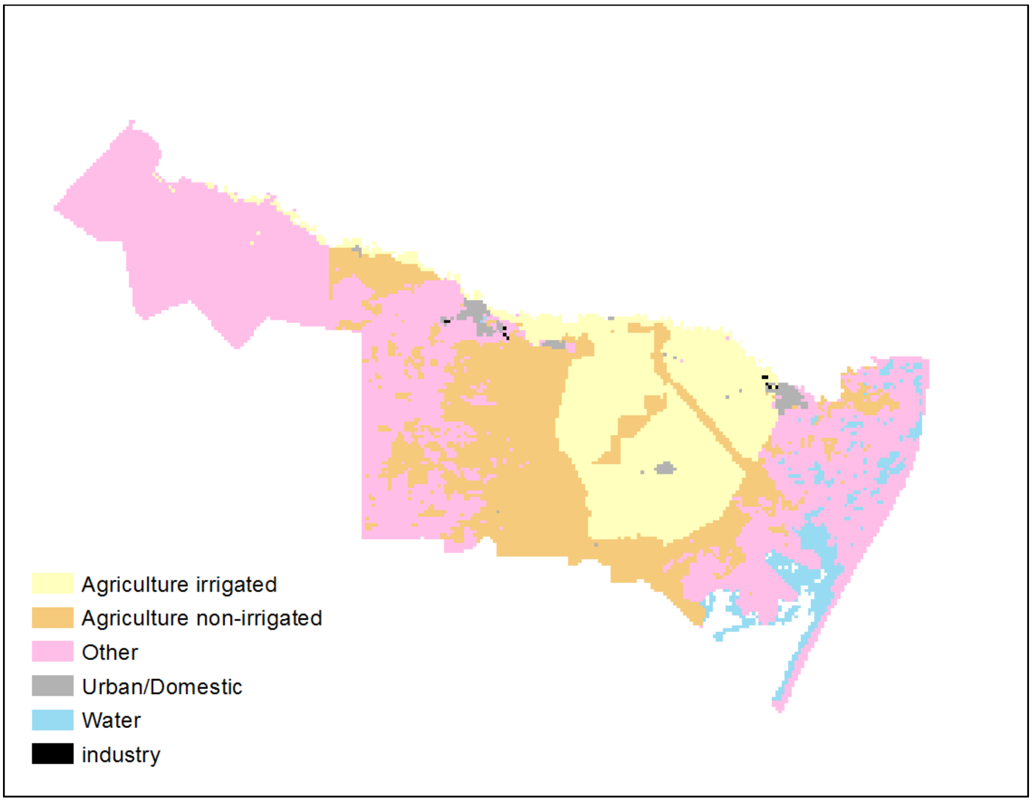


Figure 45. Land use map of the Rio Grande/Bravo Lower Basin, Mexico.

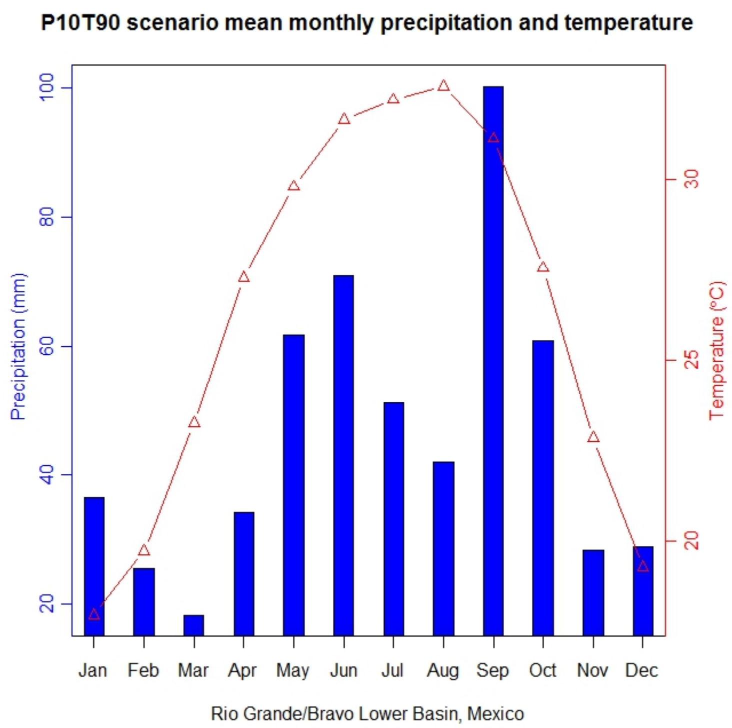


Figure 46. Mean monthly precipitation and temperature for the P10T90 scenario in Rio Grande, Mexico.

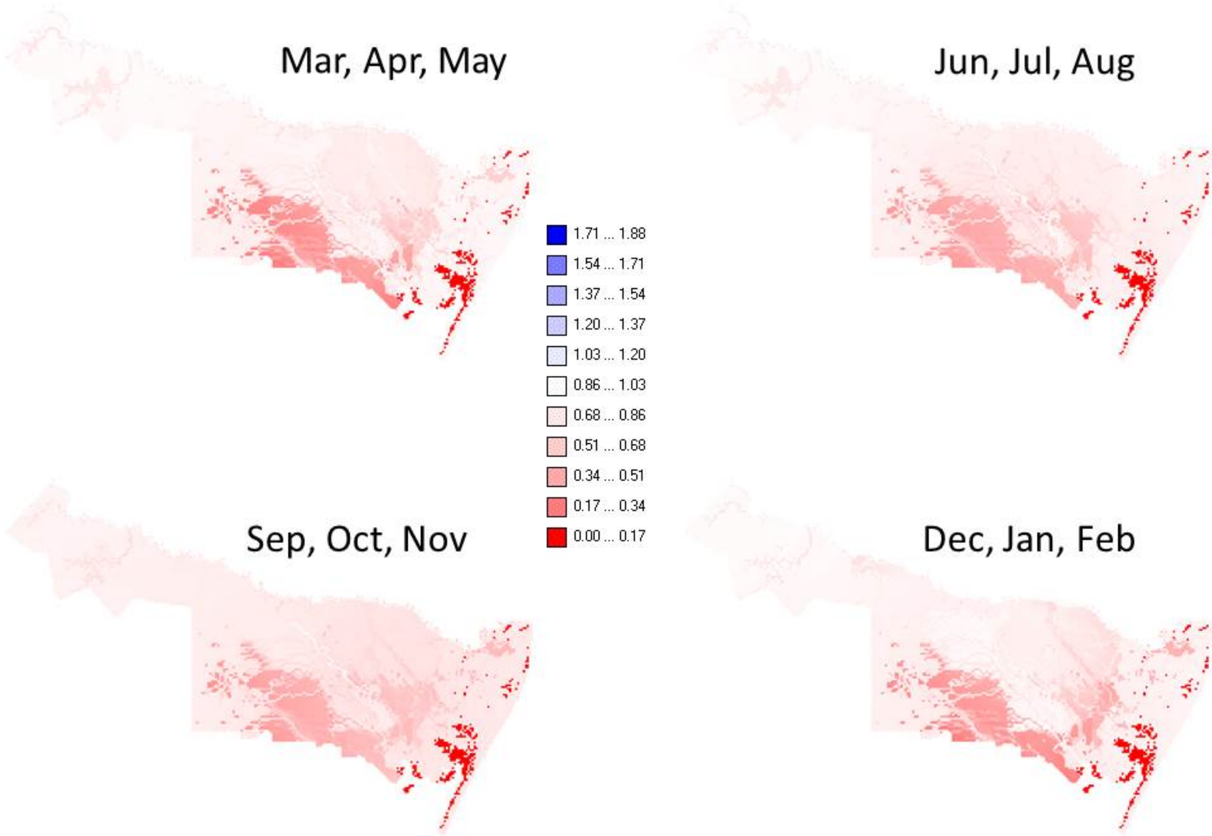


Figure 47. Ratio of P10T90 scenario discharge to baseline discharge (B/A) for all the seasons in the Rio Grande/Bravo Lower Basin, Mexico

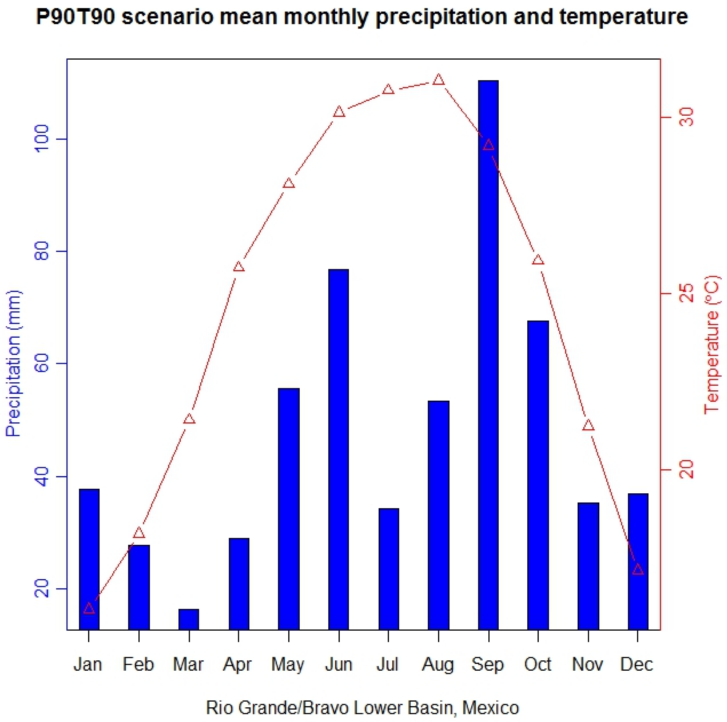


Figure 48. . Mean monthly precipitation and temperature for the P90T90 scenario in Rio Grande, Mexico.

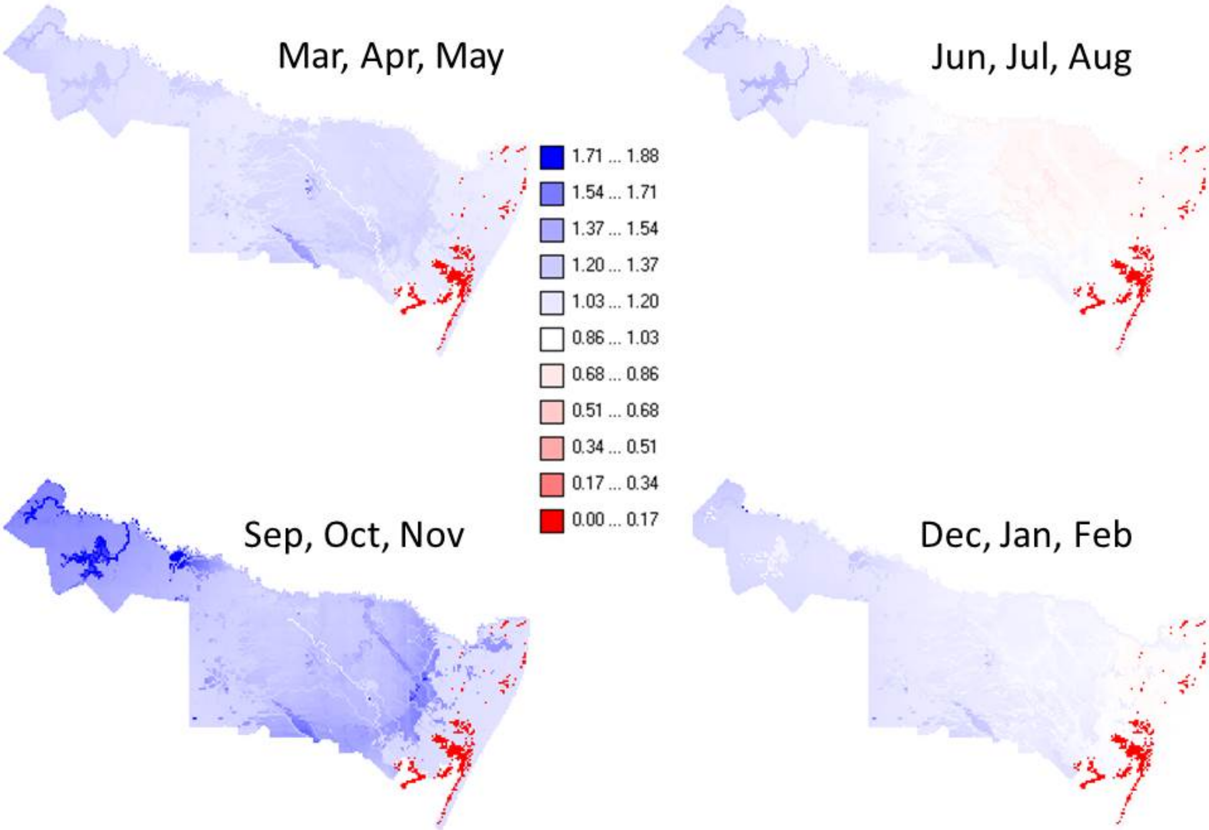


Figure 49. Ratio of P90T90 scenario discharge to baseline discharge (B/A) for all the seasons in the Rio Grande/Bravo Lower Basin, Mexico

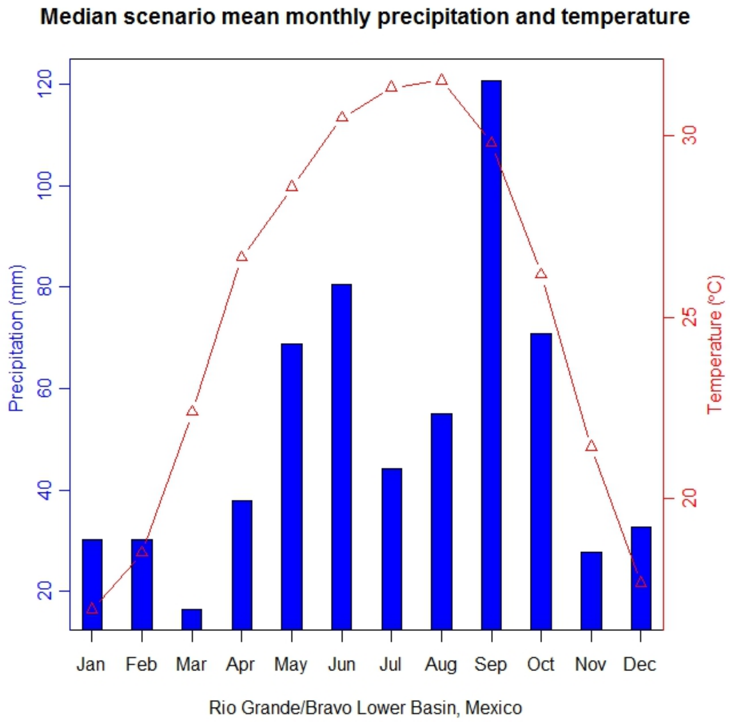


Figure 50. Mean monthly precipitation and temperature for the Median scenario in Rio Grande, Mexico.

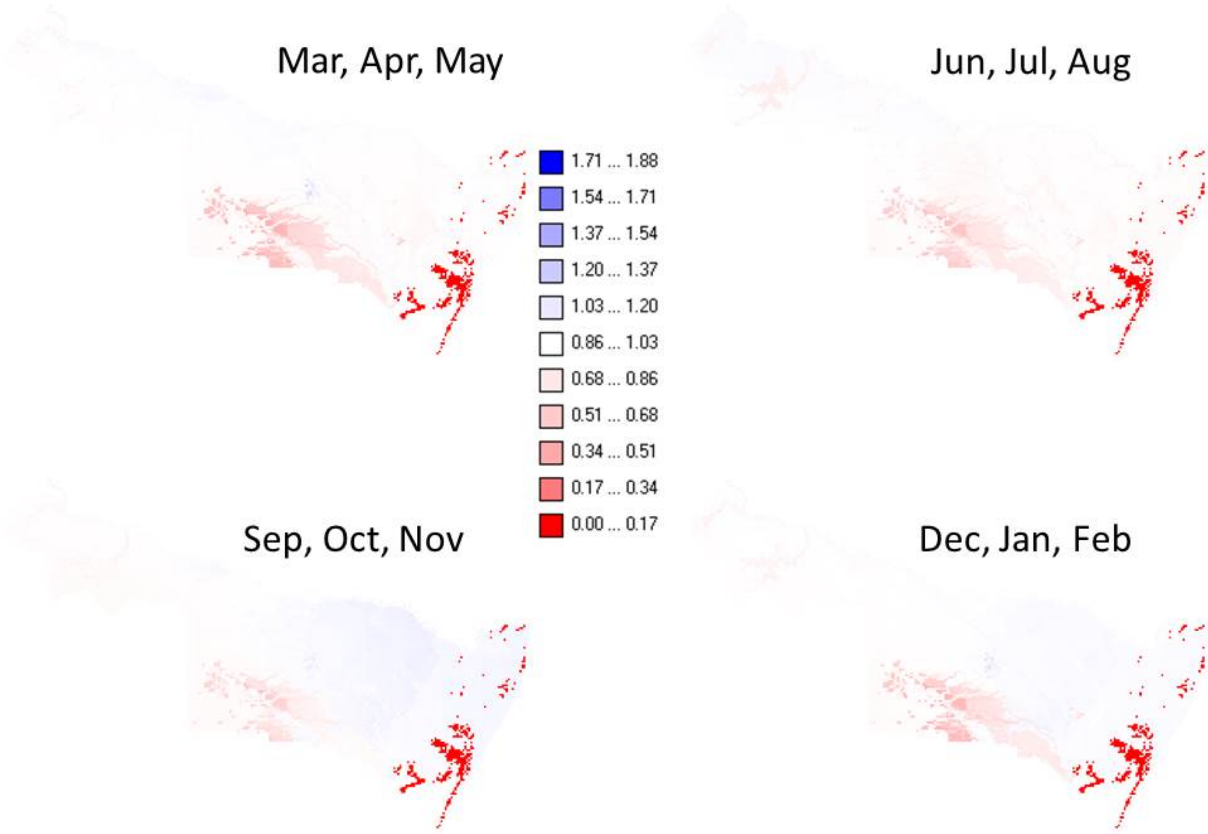


Figure 51. Ratio of Median scenario discharge to baseline discharge (B/A) for all the seasons in the Rio Grande/Bravo Lower Basin, Mexico

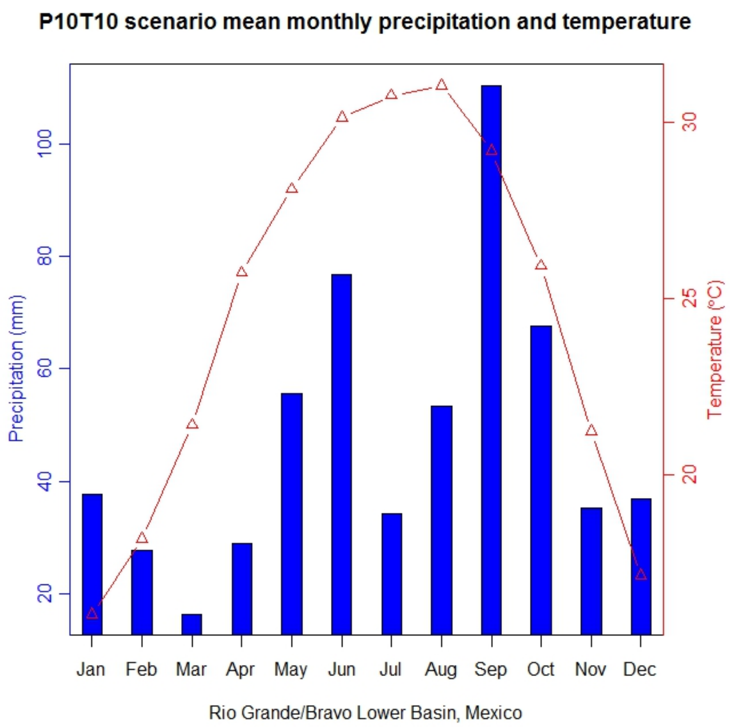


Figure 52. Mean monthly precipitation and temperature for the P10T10 scenario in Rio Grande, Mexico.

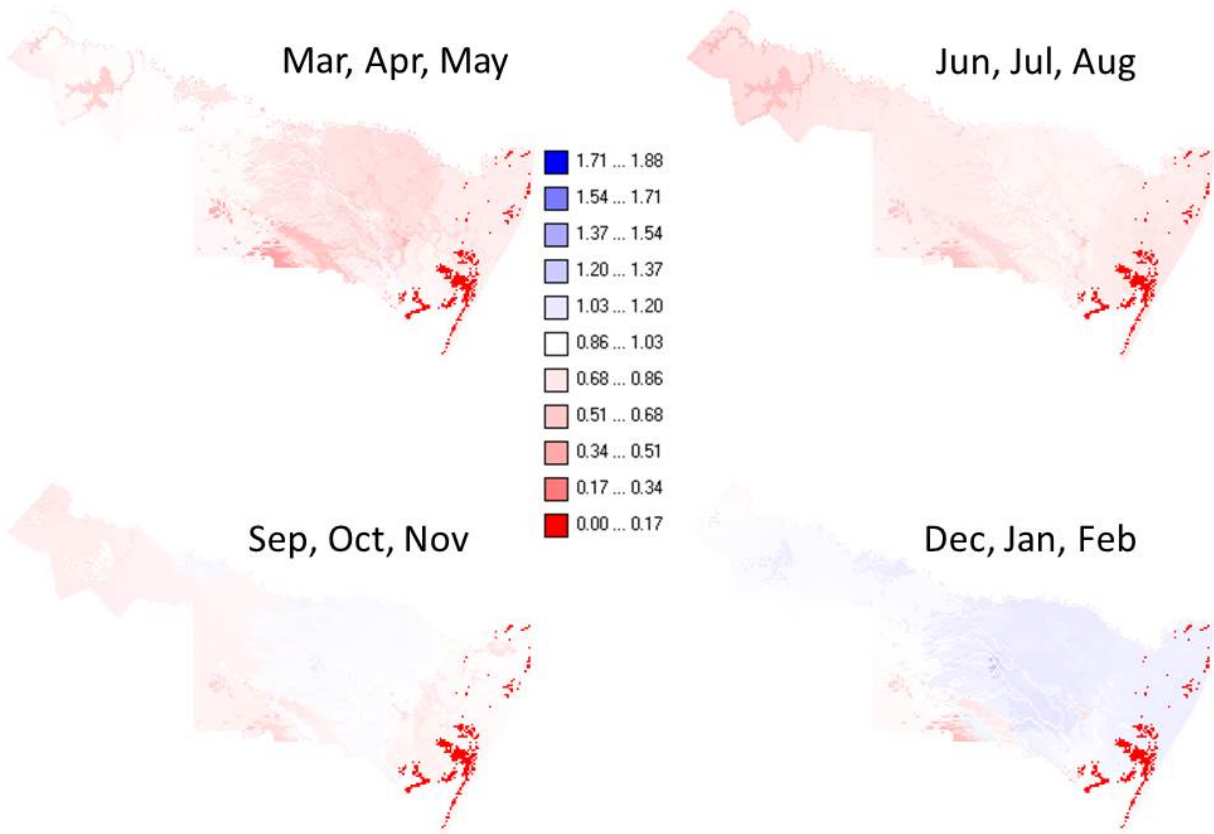


Figure 53. Ratio of P10T10 scenario discharge to baseline discharge (B/A) for all the seasons in the Rio Grande/Bravo Lower Basin, Mexico

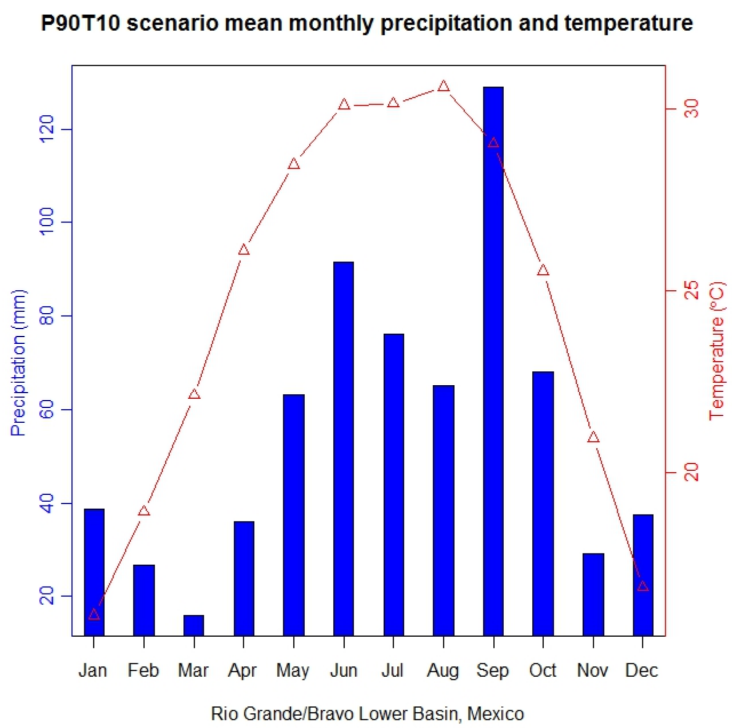


Figure 54. Mean monthly precipitation and temperature for the P90T10 scenario in Rio Grande, Mexico.

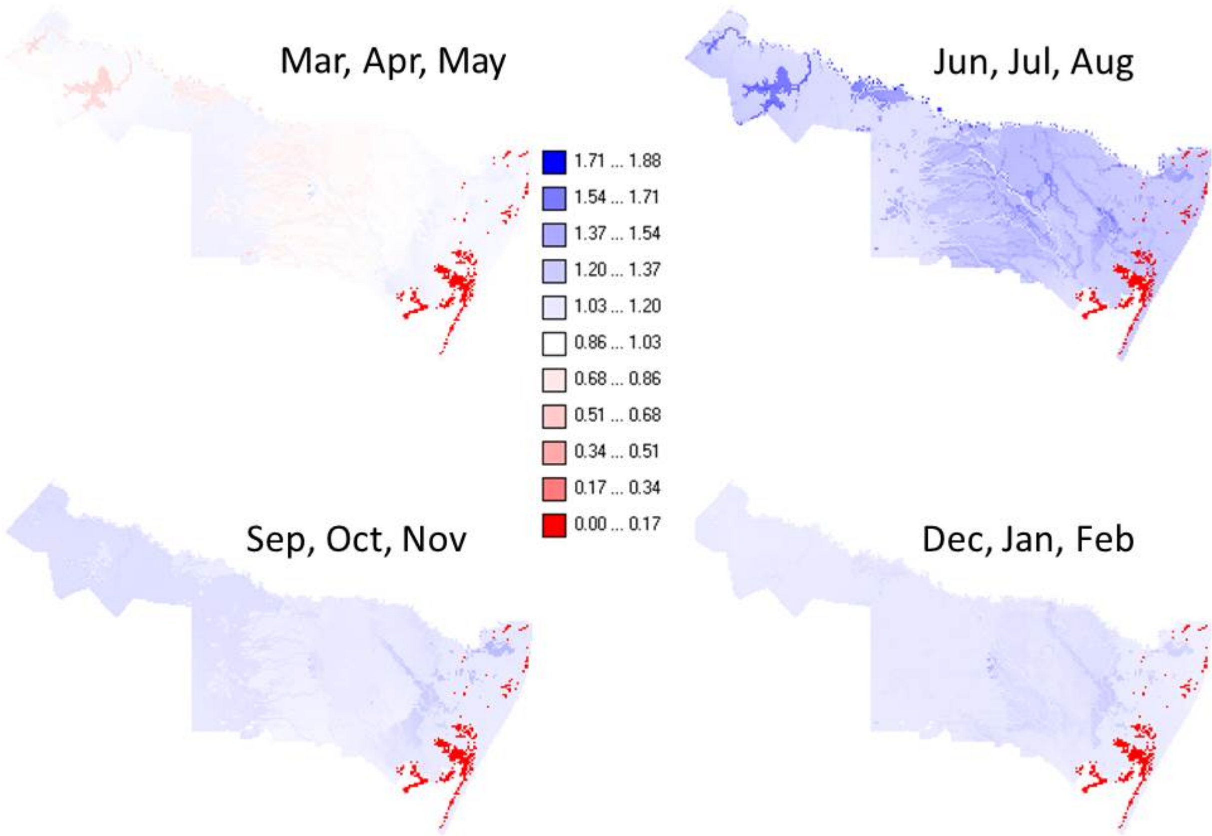


Figure 55. Ratio of P90T10 scenario discharge to baseline discharge (B/A) for all the seasons in the Rio Grande/Bravo Lower Basin, Mexico

Table 4. . Mean statistics of the ratios of scenario discharge to baseline discharge (B/A) for the 5 future scenarios

B/A average	P10T90	P90T90	M	P10T10	P90T10	mean
Mar, Apr, May	0.787	1.152	0.893	0.783	0.939	0.911
Jun, Jul, Aug	0.778	0.982	0.889	0.772	1.288	0.942
Sep, Oct, Nov	0.733	1.359	0.934	0.878	1.106	1.002
Dec, Jan, Feb	0.778	1.055	0.913	0.987	1.099	0.969
mean	0.769	1.137	0.907	0.855	1.111	

1.5 Results modelling regional domain

The modelling results of the regional domain for Latin America are calculated by the model PCR-GLOWWB. A brief outline of this global hydrological model and its performance in relation to observations is presented in chapters 1 and 2 of the main report, and will consequently not be described in this annex.

The local domain models are based on the regional domain model. However, the study sites were modelled differently in the regional and local domains. Adjustments that were made to facilitate modelling on the local domain scale were the use of:

- a smaller grid size compared to the regional domain (regional domain: ±10 km x ±10 km; local domain: ±1 km x ±1 km)
- different land use parameters. For instance, on the regional scale urban areas are too small to be distinguished as a separate land use category. However, in the local domain urban area is a land use category with its own parameter set.
- initial settings, that were based on model runs with average precipitation (period 2000 – 2010), while the initial setting of the regional domain are determined using the historical climatic conditions in a prerun.

Knowing the above-mentioned adjustments, comparing model results of the regional and local domains in detail is not meaningful. However, it makes sense to compare the order of magnitude, which is the topic of this section.

1.5.1 Catchment area of the regional and local domains

The catchment area of the case study sites was determined in the regional and local domains. It was based on the "drainage area" map using the geographical coordinates of the outlets of the study sites. Table 4.4.1 presents the catchments areas for the different domains.

Table 4.4.1 Catchment area of the case study sites according to the regional and local domains

Case study site	Catchment area local domain (km^2)	Catchment area regional domain (km^2)	Difference (%)
Suquía River Basin, Argentina	12103	13404	11
Alto Tiête River Basin, Brazil	5295	6533	23
Copiapo River Basin, Chile	16432	20776	26
Lower Rio Grande River Basin, Mexico	11178	17829	60

The catchment areas of the regional domain are bigger than the ones of the local domains, mainly due to the larger grid size. The difference in catchment area for the Mexico study site is also caused by the adjustments that were needed to simulate the Mexico study site with the local domain. The difference in catchment areas should be taken into account during the comparison of the model results of the regional and local domains.

1.5.2 Model comparison for Suquía River Basin, Argentina

Figure 4.4.1 presents the annual precipitation, actual evapotranspiration and discharge for the Argentina study site, based on the simulation results of the regional domain model. The annual precipitation during this period (2000 – 2010) is lower than the sum of the evapotranspiration and discharge. This consequently means that the storage in the soil profile of this study site is decreasing. An indication for the decreasing storage in the soil profile is the trend in the discharge. Presenting the results of figure 4.4.1 differently (not shown) shows that the trend in discharge is decreasing more than the trend in precipitation and evapotranspiration (which are alike). In fact, discharge is not only the result of the actual climatic conditions (precipitation, evapotranspiration) but also of the historic climatic conditions due to delay (retardation) within the catchment. The trend in the presented water balance components in the considered (relatively short) period is a good indicator that the storage is decreasing for this period. At this study site, the discharge is a relatively small water balance component compared to the actual evapotranspiration.

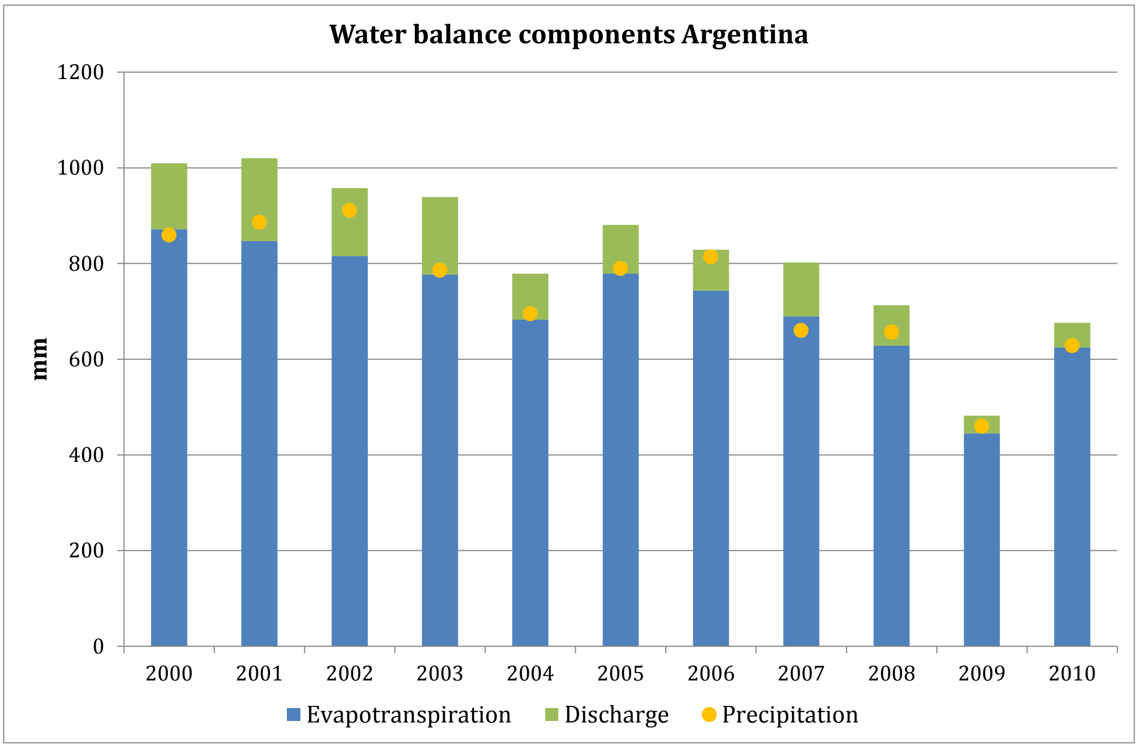


Figure 4.4.1 Annual water balance components for the Argentina study site, based on the simulation results of the regional domain model.

The mean monthly discharge at the outlet of the Argentina catchment according to the regional and local domain modelling results is presented in figure 4.4.2. The mean monthly discharge of the local domain is higher (on average two times) and shows more variation between the months than the mean monthly discharge of the regional domain. Also notice that for this study site the standard deviation in the regional results does not vary much. Some of the lack of variation in the regional domain can be attributed to the buffering effect of the larger grid size in the regional domain.

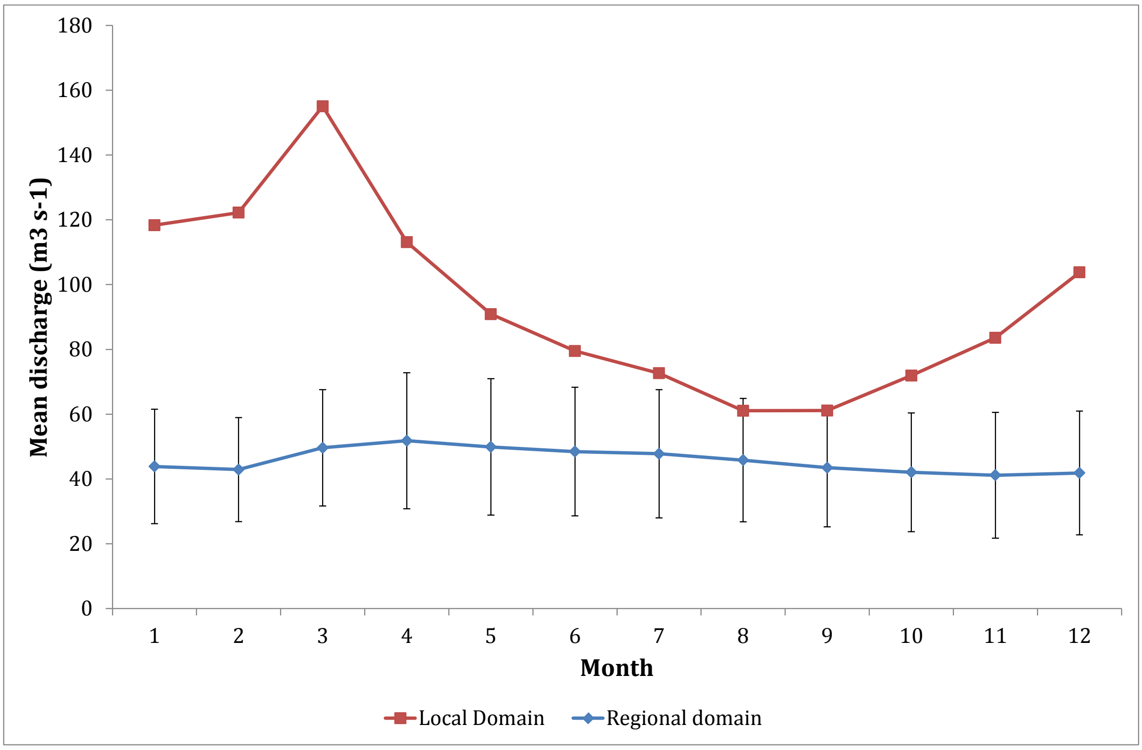


Figure 4.4.2 Mean monthly discharge at the outlet of the Argentina catchment according to the regional and local domain modelling results (period 2000 – 2010). For the regional domain standard deviations are presented in the error bars.

1.5.3 Model comparison for Alto Tiête River Basin, Brazil

Based on the simulation results of the regional domain model, the annual precipitation, actual evapotranspiration and discharge for the Brazil study site are presented in figure 4.4.3. During this period (2000 – 2010) the annual precipitation is on average higher than the sum of the evapotranspiration and discharge. The trend in precipitation during this period is increasing. Since the evapotranspiration at this study site shows little variation during the period, more water is available for discharge and storage. An increasing trend in discharge is observed in data of figure 4.4.3 (not shown). The actual evapotranspiration in Brazil is on average slightly higher than in Argentina. The discharge in Brazil, however, is much higher than in Argentina. In fact, in the study site of Brazil discharge is the biggest "outgoing" water balance component.

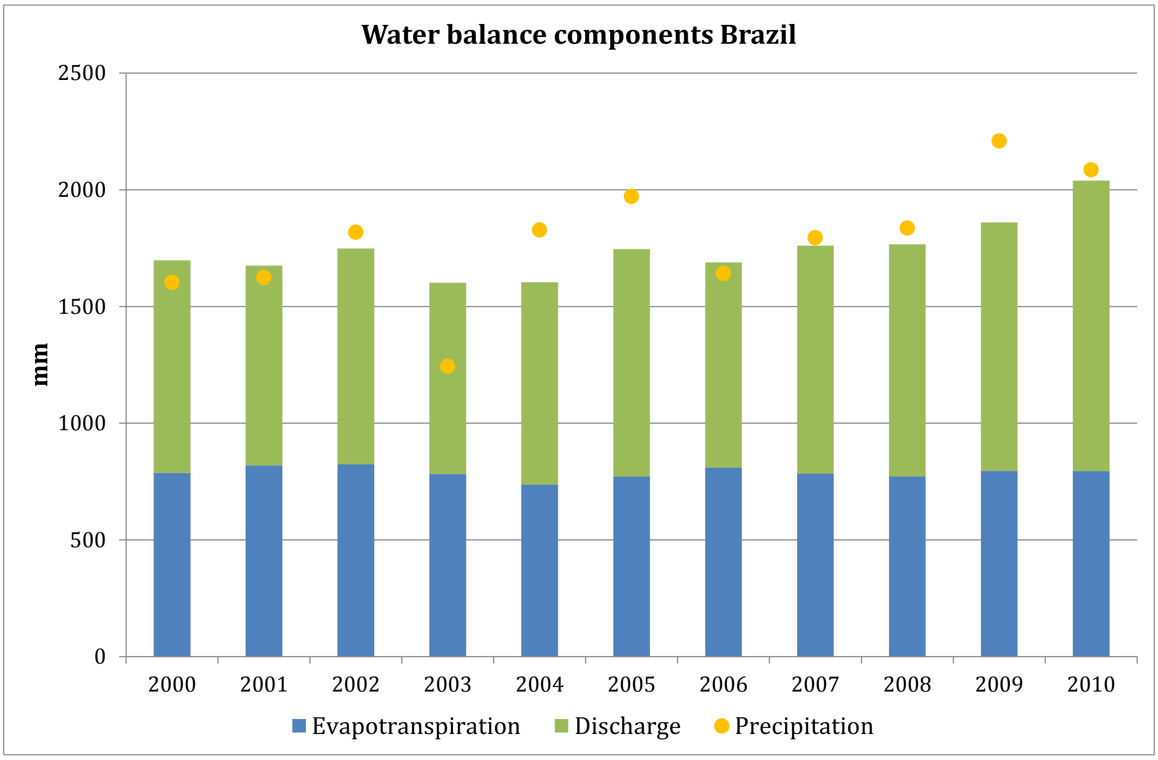


Figure 4.4.3 Annual water balance components for the Brazil study site, based on the simulation results of the regional domain model.

Figure 4.4.4 presents the mean monthly discharge at the outlet of the Brazil catchment according to the regional and local domain modelling results. The mean monthly discharge of the regional domain is on average slightly higher than the mean monthly discharge of the local domain. The variation between the months is smaller in the regional domain results compared to the local domain results (see also the "regional" standard deviation in figure 4.4.4). Lack of variation in the regional domain can partly be attributed to the buffering effect of the larger grid size. The average discharge for the period (2000 – 2010) of the Alto Tiête River (catchment study area) is 198 and 168 m^3/s for the regional and local domain respectively.

1.5.4 Model comparison for Copiapo River Basin, Chile

The annual precipitation, actual evapotranspiration and discharge for the Chile study site (based on the simulation results of the regional domain) are presented in figure 4.4.5. During the presented period (2000 - 2010) the sum of the annual evapotranspiration and discharge is on average nearly equal to the precipitation.

The annual precipitation in the Chile study area is very low compared to the precipitation in the Argentina and Brazil study areas. Most of the precipitation in the Chile study site is "lost" as a result of the evapotranspiration. The potential evapotranspiration (evapotranspiration due to the atmospheric demand) is much higher but is limited as a result of the shortage of water in the soil profile. Discharge in the Chile study site is a minor water balance component.

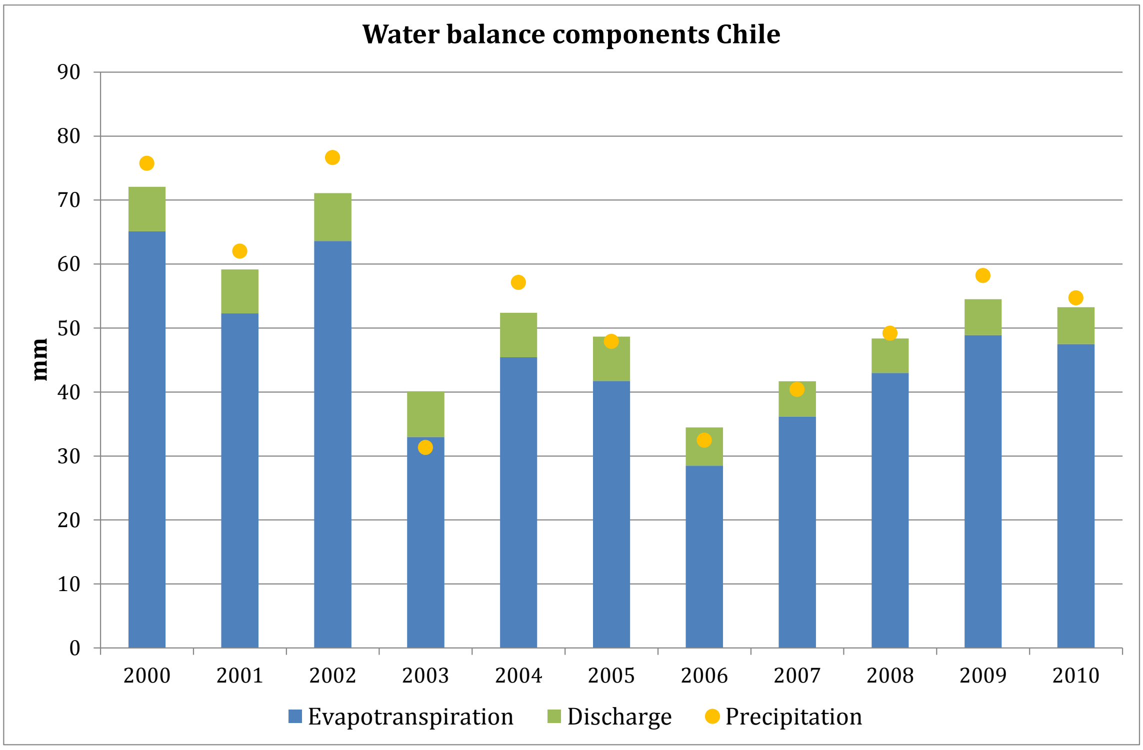


Figure 4.4.5 Annual water balance components for the Chile study site, based on the simulation results of the regional domain model.

The mean monthly discharge at the outlet of the Chile catchment according to the regional and local domain modelling results is presented in figure 4.4.6. Although both mean monthly discharges are very low and hardly vary between the months, the mean monthly discharge of the regional domain is the highest.

1.5.5 Model comparison for Lower Rio Grande River Basin, Mexico

Because of the major adjustments in the local simulation of the Mexico study site, results of the local and regional domain are not comparable. So, we decided not to pay any attention to the comparison of the local and regional modelling results for the Mexico study site.

1.5.6 Model comparison regional domain versus local domains

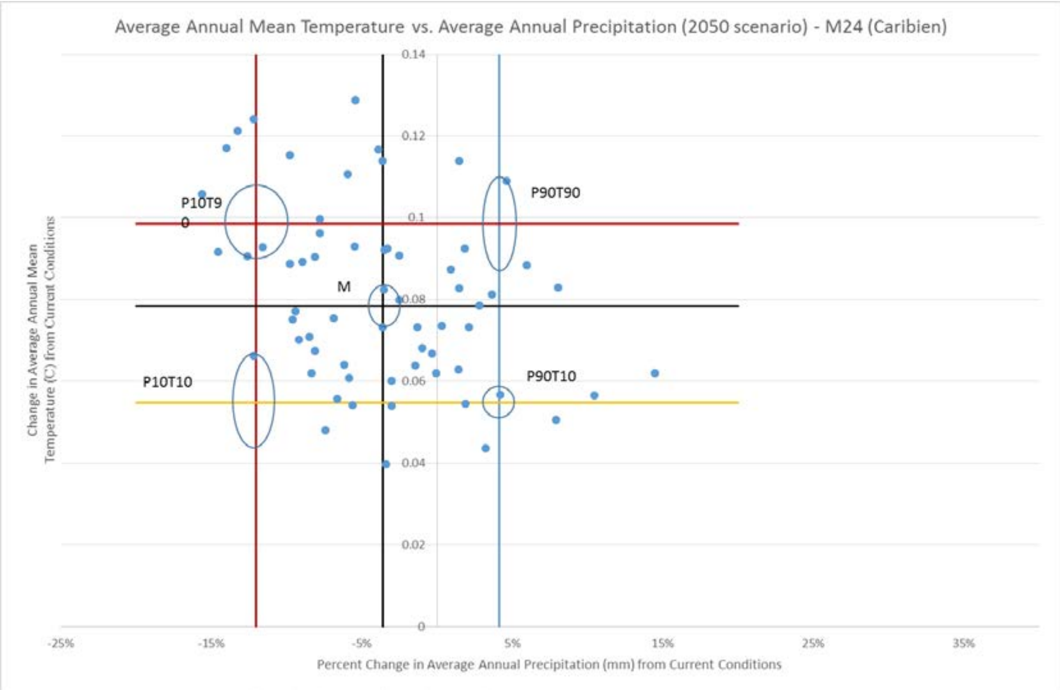
The yearly sum of the precipitation for the study sites according to the regional domain (Latin America) and the local domains were compared. The differences in precipitation can be large. In some years the local precipitation for Brazil and Chile is larger than the regional precipitation. In other years, the opposite is true. For Argentina, the local precipitation is always larger or equal to the regional precipitation. The differences in precipitation are caused by:

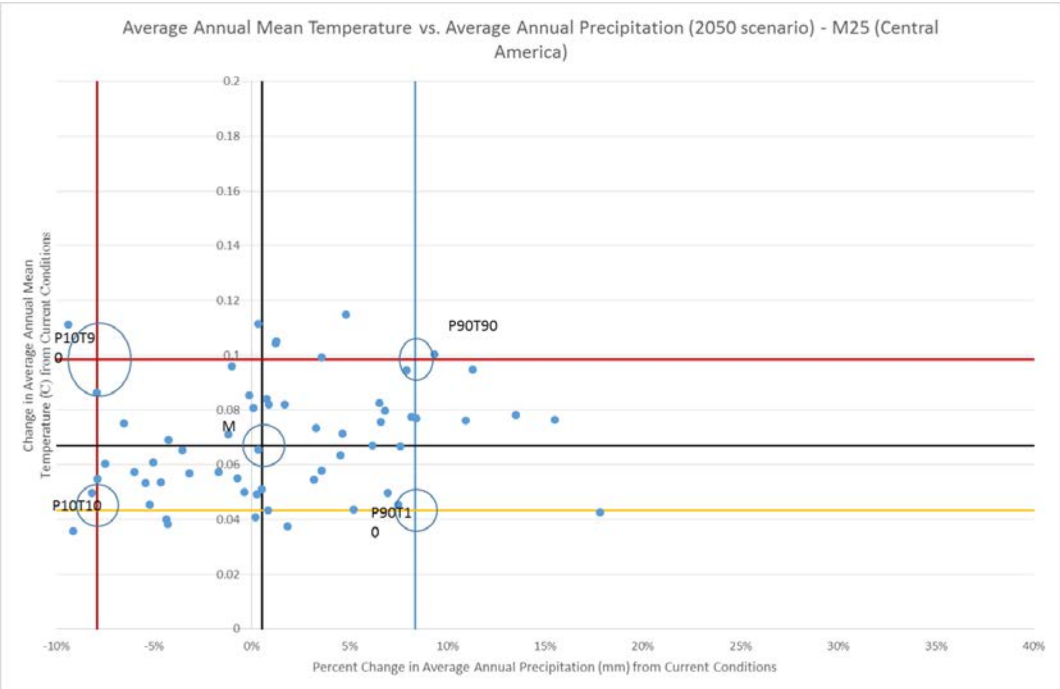
- the resampling procedure. The precipitation (and reference evapotranspiration and temperature) for the regional and local domains are basically all based on the same climatic data. However, the climatic data had to be resampled (scaled down) to the desired grid size of the different domains. Besides the fact that the used resampling methods may result in different precipitation patterns, resampling to different grid sizes also will result in different precipitation patterns. Basically both domains use the same climatic dataset (ECMWF re-analysis: ERA-40 and ERA-interim; http://www.ecmwf.int/). However, the dataset used for the regional domain is a slightly updated version than the one used for the local domains. It is expected that the difference in regional and local precipitation is mainly caused by resampling to the different grid sizes. The yearsum of the actual evapotranspiration for the study sites, regional domain versus local domains, were also compared. The regional actual evapotranspiration for Argentina and Brazil is larger than the local actual evapotranspiration. The main reasons for these differences are: differences in land cover parameters. The land cover parameters for the regional domain are based on GLCC. For the local domains, local land cover maps where used to determine the land cover parameters.

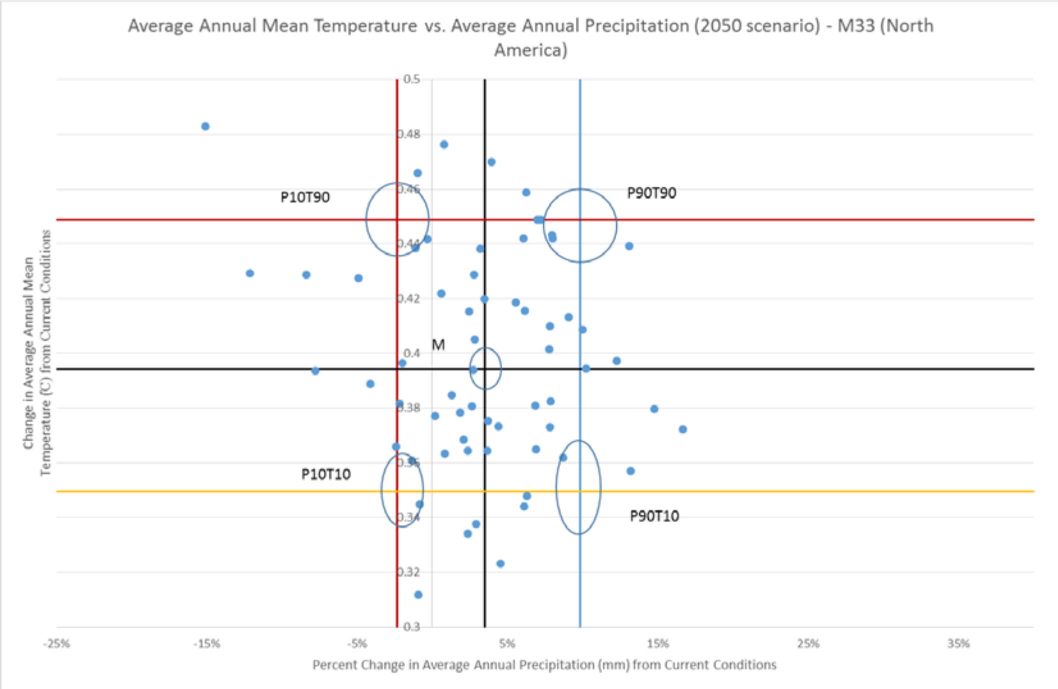
- differences in the (resampled) temperature and reference evapotranspiration.
- differences in the initial conditions. Local initial conditions were based on model runs with average precipitation, while regional initial conditions were determined using the historical climatic data in a prerun.

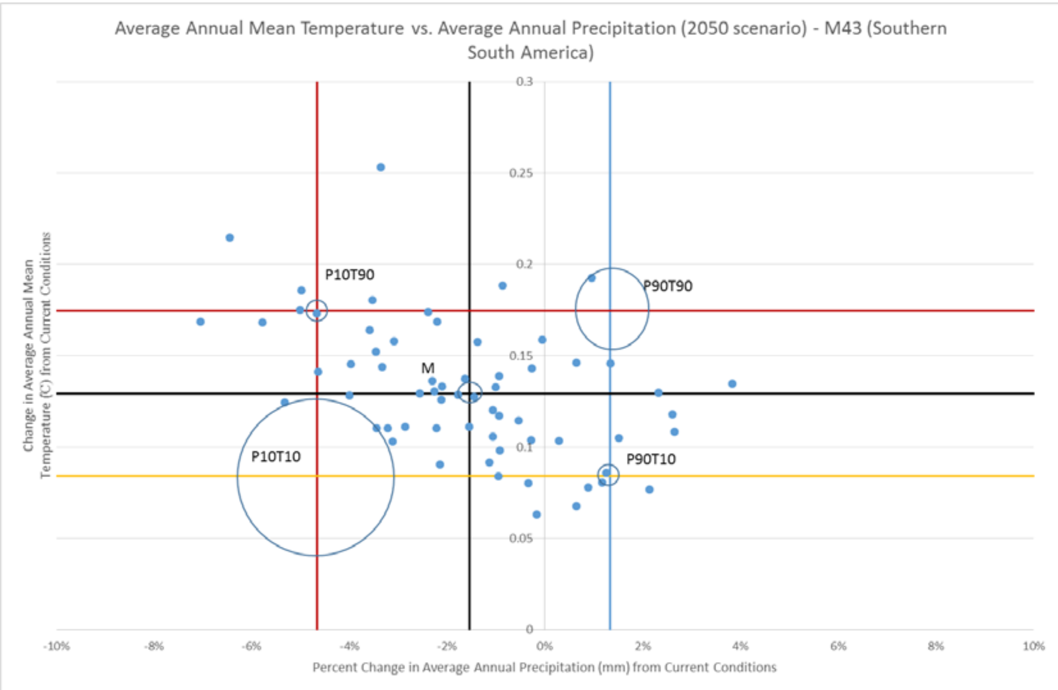
Finally the yearsum of the discharge was compared for the study sites: regional domain versus the local domains . The local discharge for Argentina and Brazil is larger than the regional discharge. For Argentina, this is expected because local precipitation is also larger and the local actual evapotranspiration is lower. For Brazil, explaining the larger local discharge is much more complex, since the local precipitation and local actual evapotranspiration are lower than the regional ones. Unfortunately, we are not able to see the change in soil storage for the regional domain, to see if this explains the observations.

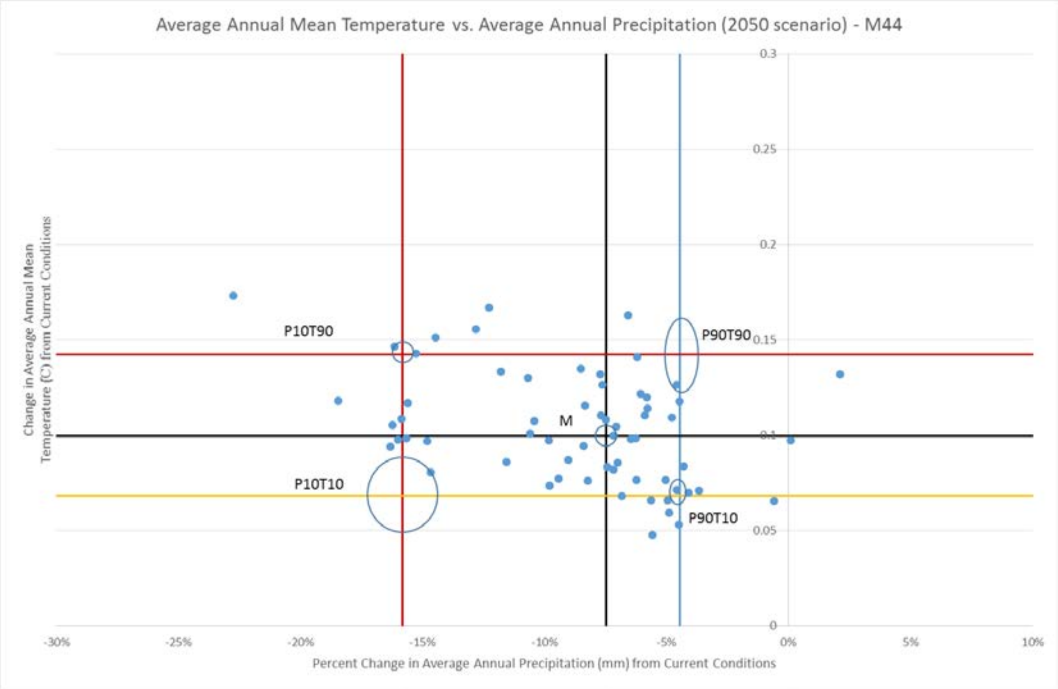
1.6 Figures of CCM selection for the Latin-American domain

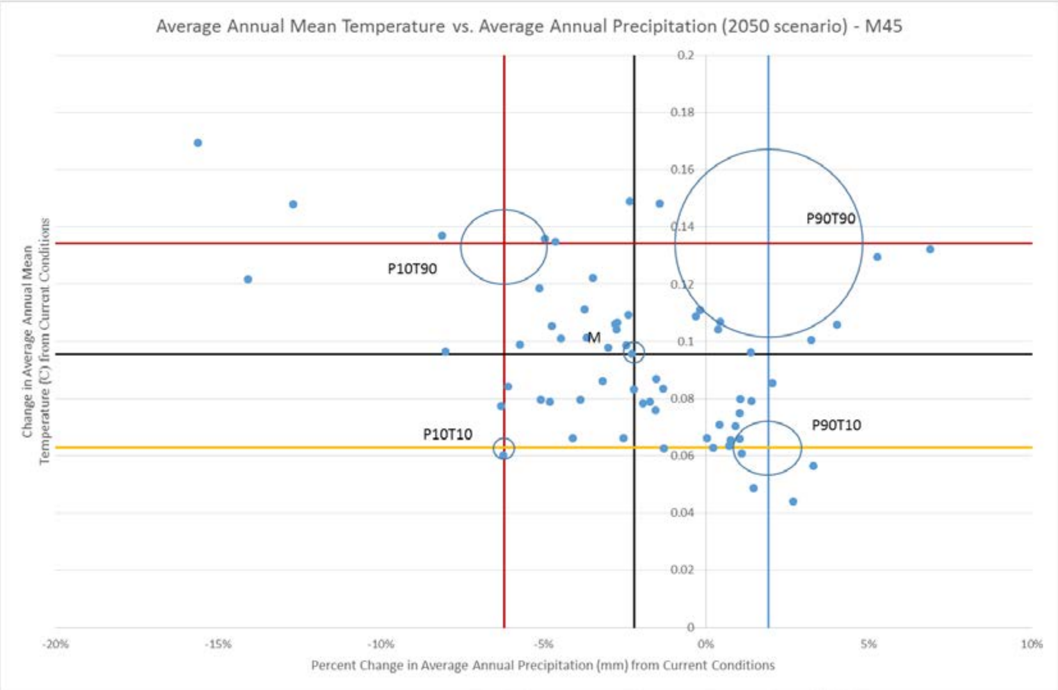


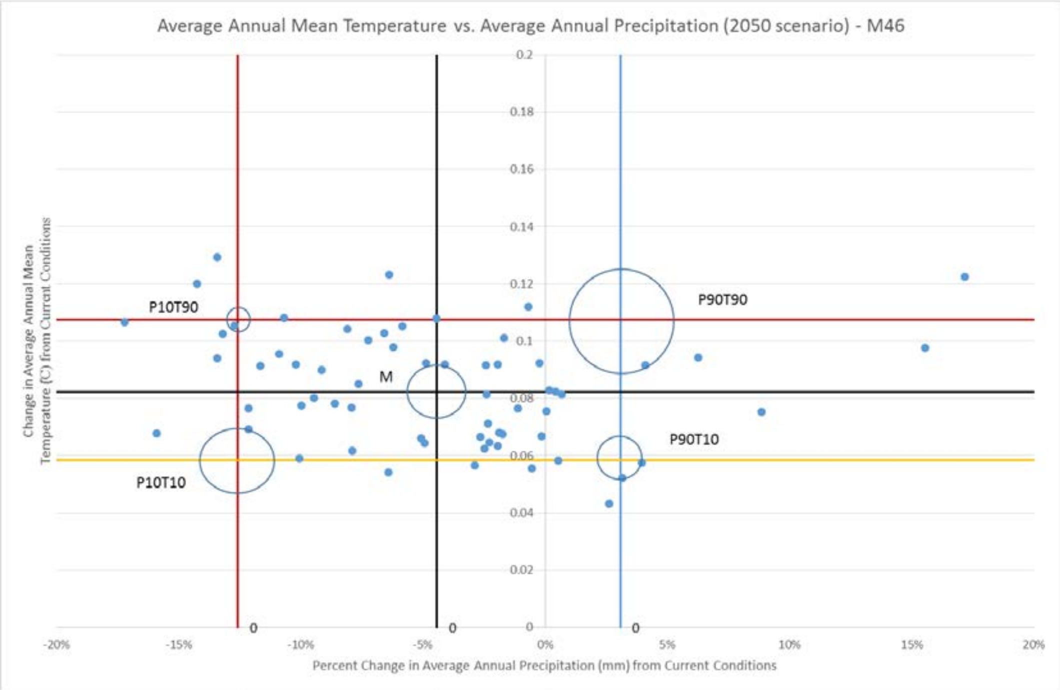



Average Annual Mean Temperature vs. Average Annual Precipitation (2050 scenario) - M33 (North America)
P10T90
P90T90
M
P10T10
P90T10
Change in Average Annual Mean Temperature (C) from Current Conditions
Percent Change in Average Annual Precipitation (mm) from Current Conditions


Average Annual Mean Temperature vs. Average Annual Precipitation (2050 scenario) - M43 (Southern South America)
P10T90
P90T90
M
P10T10
P90T10
Change in Average Annual Mean Temperature (C) from Current Conditions
Percent Change in Average Annual Precipitation (mm) from Current Conditions


Average Annual Mean Temperature vs. Average Annual Precipitation (2050 scenario) - M44
Change in Average Annual Mean Temperature (C) from Current Conditions
Percent Change in Average Annual Precipitation (mm) from Current Conditions
P10T90
P90T90
M
P10T10
P90T10
0.3
0.25
0.2
0.15
0.1
0.05
0
-30%
-25%
-20%
-15%
-10%
-5%
0%
5%
10%


Average Annual Mean Temperature vs. Average Annual Precipitation (2050 scenario) - M45
Change in Average Annual Mean Temperature (C) from Current Conditions
Percent Change in Average Annual Precipitation (mm) from Current Conditions
P10T90
P90T90
M
P10T10
P90T10
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-20%
-15%
-10%
-5%
0%
5%
10%


Average Annual Mean Temperature vs. Average Annual Precipitation (2050 scenario) - M46
Change in Average Annual Mean Temperature (C) from Current Conditions
Percent Change in Average Annual Precipitation (mm) from Current Conditions
P10T90
P90T90
M
P90T10
P10T10
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-20%
-15%
-10%
-5%
0%
5%
10%
15%
20%

1.7 Scenarios regional scale

Figure 8.3.1 - 8.3.5 present maps with the relative change in mean monthly discharge for Latin America according to the regional domain modelling results for the five future climatic scenarios. The relative change maps are basically constructed by calculating the relative difference between a scenario and the baseline situation ((scenario – baseline)/ baseline*100). Negative values (darker colours) mean that the modelled discharge in the scenario simulation is less than the modelled discharge in the baseline simulation. Positive values (lighter colours) mean an increase in the modelled scenario discharge compared to the baseline discharge.

Note the abrupt change in Figure 8.3.5 (T10P90) around 20 degrees south. This abrupt change corresponds with the border between two regions that were used in the future climatic scenario selection procedure. The chosen scenarios for the corresponding regions apparently differed, resulting in the abrupt change for the T10P90 scenario. In the other scenarios, no obvious abrupt changes are visible. Overall, the variations within a region are larger than the variations between regions.

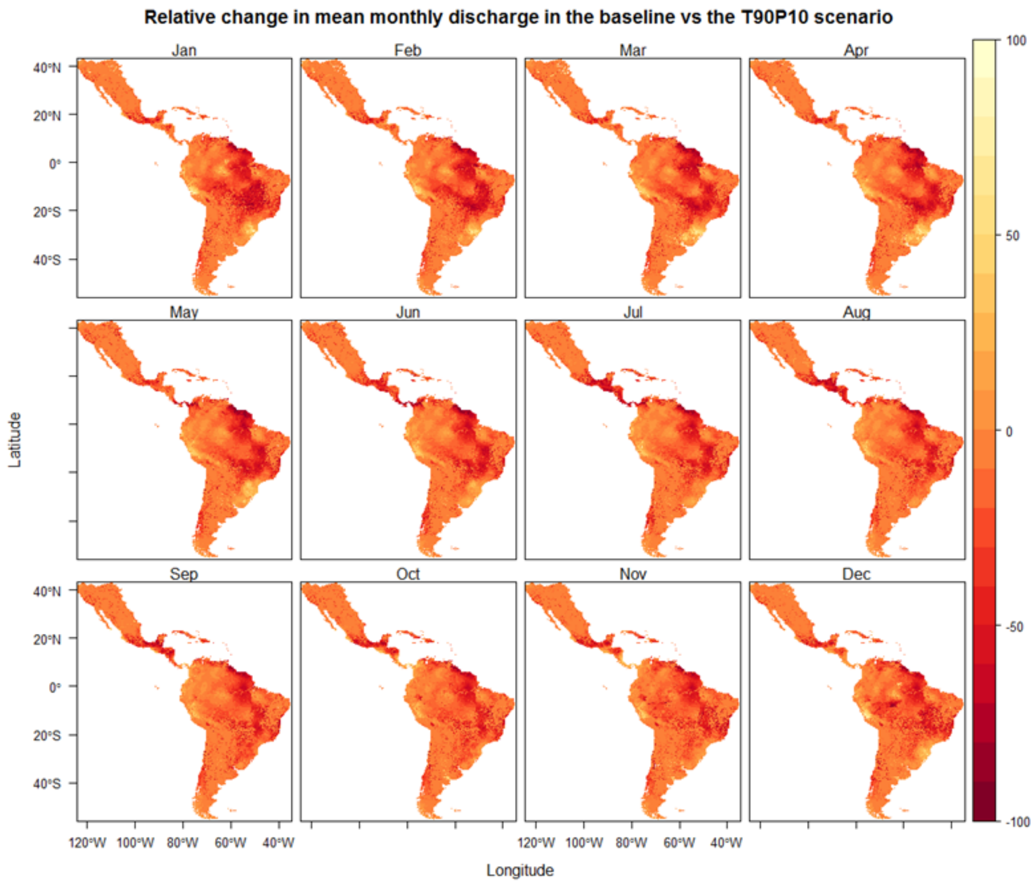


Figure 8.3.1 Maps with relative change in mean monthly discharge per month for Latin America according to the regional domain modelling results for the T90P10 scenario 'minus' the baseline situation.

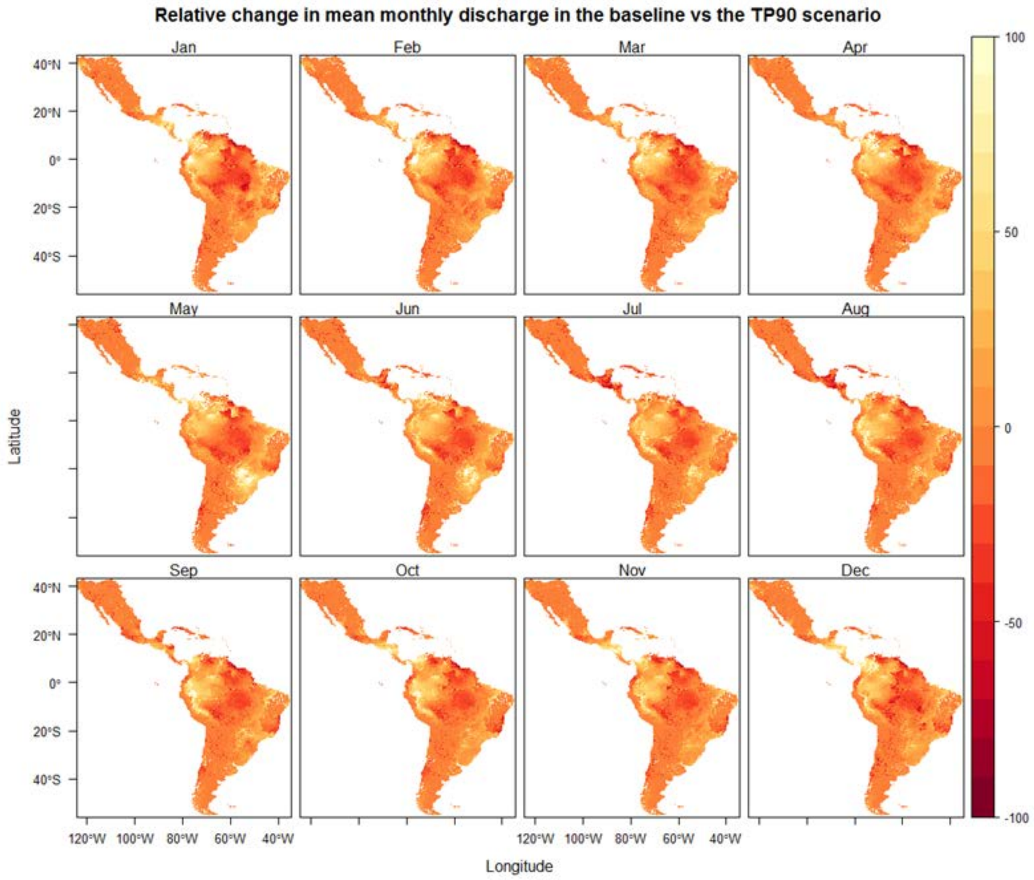


Figure 8.3.2 Maps with relative change in mean monthly discharge per month for Latin America according to the regional domain modelling results for the T90P90 (= TP90) scenario 'minus' the baseline situation.

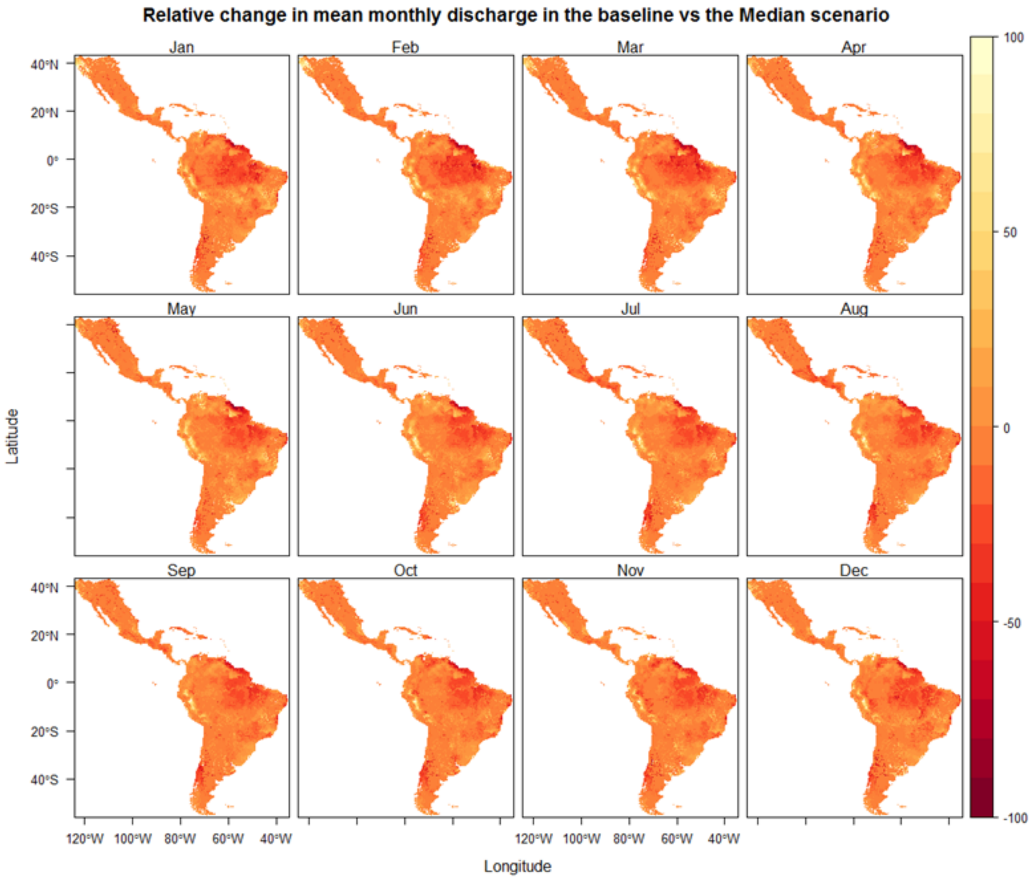


Figure 8.3.3 Maps with relative change in mean monthly discharge per month for Latin America according to the regional domain modelling results for the Median scenario 'minus' the baseline situation.

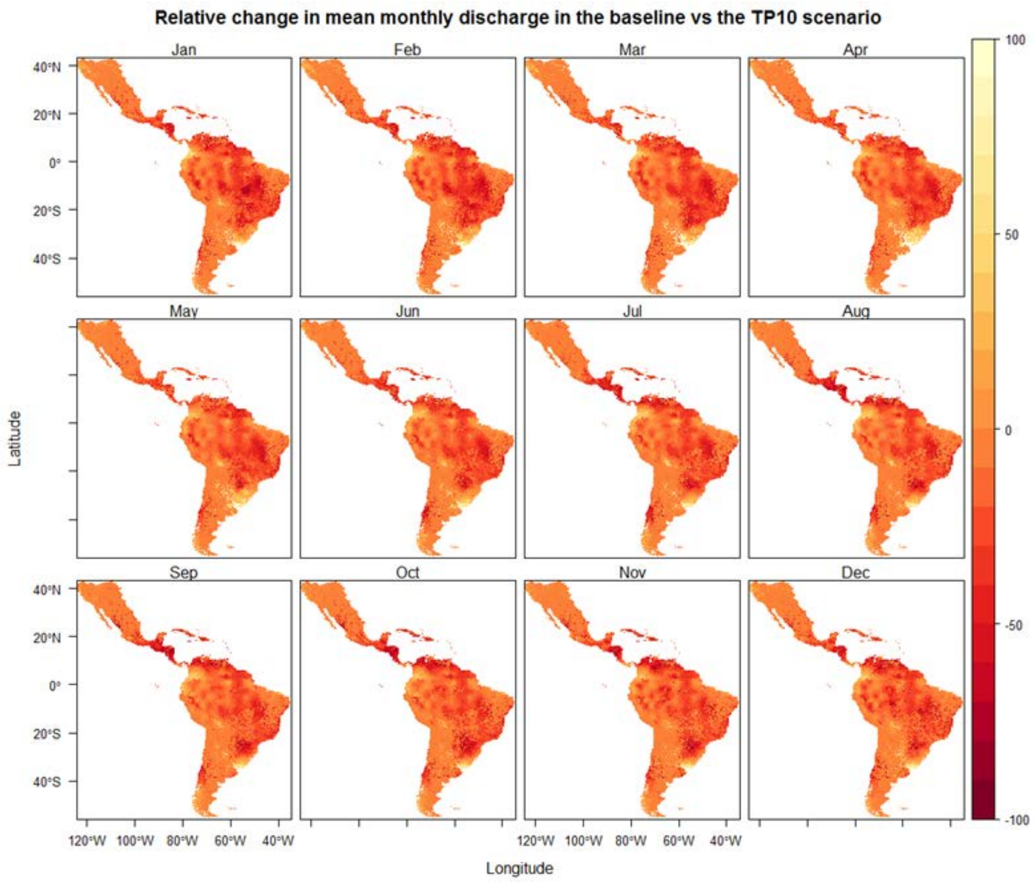


Figure 8.3.4 Maps with relative change in mean monthly discharge per month for Latin America according to the regional domain modelling results for the T10P10 (=TP10) scenario 'minus' the baseline situation.

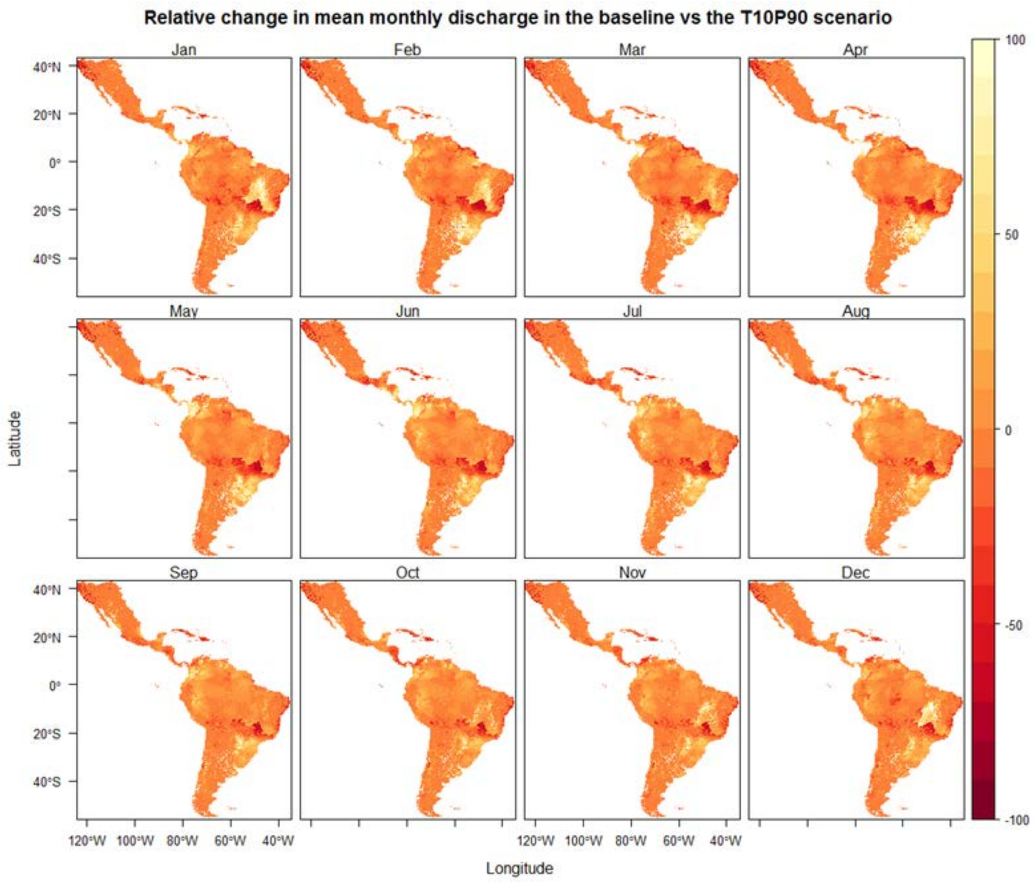


Figure 8.3.5 Maps with relative change in mean monthly discharge per month for Latin America according to the regional domain modelling results for the T10P90 scenario 'minus' the baseline situation.

1.8 Configuration file for incorporating the PCRGLOBWB model in the COROADO DSS

```
####################################################################################
# PCR-GLOBWB V1.0 - Utrecht University 2014, created by Rens van Beek        #
####################################################################################
# This configuration file specifies the settings of the pure PCRaster version
# of the PCRaster Global Water Balance model (PCR-GLOBWB).
# It includes settings for the water balance component and the routing
# component which can be run optionally. The model temporal resolution is
# currently limited to the daily time step on which it is run sequentially
# per individual year.
#
# The configuration script is read and processed by the python standard module
# ConfigParser and follows python conventions, e.g., in relation to paths and
# argument substitution, the latter being used e.g. to handle dates in relation
# to the native, time-naive PCRaster format. camelCase is used throughout and
# the single backward slash is the line continuation character.
# Maps can be specified by file names and refer to standard PCRaster maps
# of indetermined length and with the default .map extension, as PCRaster
# stack of maps for different time steps following a MS-DOS 8.3 name
# convention in which time is expressed by the extension (e.g., rain0000.366
# for the rain on the last day of a leap year). Alternatively, input can be
# provided by netCDF files on a regular grid in which time can be specified
# by means of a separate time dimension.
#
# The configuration files lists for each section relevant input and output
# variables and possible options. Sections are included in square brackets.
# Land cover and meteorological forcing expect several subsections that are
# specified below.
# Values for the different variables are specified by "variableName= value"
# where value can consist of a single number, a sequence of numbers or
# arguments, the name of a single map or the root of a map stack
# using argument substitution.
#
# By using argument substitution and relative and absolute paths it is possible
# to configure the model with a high degree of flexibility (e.g., use land cover
# conditions that vary over the years; specify transient and time slice climate
# anomalies to evaluate the impacts of climate change). Note that the model
# substitutes sparse time values, updating them when available, similar
# to the PCRaster timeinputsparse() command.
#
# Input does not have to match the clone and will be automatically resampled
# where it is implicitly assumed that all input is on a regular grid and has
# an extent that covers the clone map. However, for the sake of speed and
# transparency, it may be advisable to adhere to the native PCRaster format
# for maps that match the clone accurately with the exception of the
# meteorological input for which this may become cumbersome. Note that it is
# possible to report the meteo forcing and write it to netCDF which may be
# useful and efficient in the case of recurrent use.
# Avoid names with spaces
####################################################################################

# globalSettings: specifies global options to run the model; start and end date
# of the model run in python datetime format (e.g.,2000-12-31 00:00:00); time
# is optional. Currently, the model assumes full years to be simulated and
# to be provided as input. Only days can be modelled at present.
# Spin-up can be specified to initialize the various stores before the actual
# model run and to remove any error in the provided initial conditions.
# The definition of spin-up is simple, consisting of a number of years
# that respectively the water balance component is run stand-alone
# and that the routing model is run stand-alone, if required.
# If the no routing is simulated, the latter is ignored. Spinup is performed
# by repeatedly modelling a specified year. If not specified or present, the
# first year is used by default. More advanced spin-up options could be
# imposed by means of a separate configuration file or running a simulation
# period back-to-back. If both spin-up periods are zero, no spin-up is
# performed. If inconsistent, the spin-up period is set to a mimimum length
# of 1 year.
# title                 :  simulation title
# startDate             :  start date of the simulation
# endDate               :  end date of the simulation
# timeStep              :  length of the time step in the unit specified
# timeStepUnit          :  datetime.timedelta object (e.g., days)
# spinupWaterBalance    :  number of times the first year is run to
#                          warm-up the vertical water balance
# spinupRouting         :  number of times the first year is run to
#                          warm-up the routing component, following
#                          the spin-up of the water balance component
```

```
#
                                        and using the specific runoff fields
# spinupYear          :  the year that is used repeatedly for spinup
# landCoverTypes      :  land cover types -in addition to the default
#                  freshwater surface specified for the routing
#                  section- as used by the water balance component
#                  for which the parameters are specified below;
#                  this takes the form of a list of names that are used
#                  to identify separate subsections for the land cover
#                  with input below.
[globalSettings]
title= Standard simulation with PCR-GLOBWB V1.0
startTime= 2000-01-01 #1958-01-01 #NH aanpassen
endTime= 2005-12-31                  #2010-12-01 #NH aanpassen
timeStep = 1.0
timeStepUnit = days
spinupWaterBalance= 1 #10 #NH aanpassen
spinupRouting= 1 #5 #NH aanpassen
spinupYear= 2002 #1958 #NH aanpassen
landCoverTypes= tallVegetation, shortVegetation

# fileManagementSettings: specifies the general input and output locations
# inputRootDirectory    :  input directory; all relative data paths are
#                  assumed to reside under here
# outputRootDirectory   :  output directory; all relative output paths
#                  are assumed to reside under here
# resultsDirectory      :  output directory, relative or absolute, to hold
#                  the selected output
# statesDirectory       :  directory, relative or absolute, to the hold the
#                  initial states imposed and created by the model
# logDirectory          :  directory, relative or absolute, to hold run logs
# scratchDirectory      :  temporary scratch directory, relative or absolute
#                  that will hold the temporary model output; is
#                  cleaned upon exit
#
# Note that under windows backward slashes have to be doubled, e.g.,
# inputRootDirectory= C:\\My Documents\\pcrSim01; absolute paths are
# denoted by the inclusion of the drive letter.
# Under Linux, absolute paths are denoted by the trailing forward slash,
# relative paths by the absence thereof.
# Setting the inputRootDirectory and outputRootDirectory to None or
# omitting them wil run the model in the directory where the model resides.
[fileManagementSettings]
inputRootDirectory= E:\\Projecten\\Coroado\\Data_LatinAmerica\\PRC_LatinAmerica_Parameterization_05min #NH
outputRootDirectory= None
resultsDirectory= LA_results_M33 #NH aanpassen
statesDirectory= LA_states_M33 #NH aanpassen
logDirectory= LA_log_M33 #NH aanpassen
tempDirectory= temp

# netCDFAttributes: specifies the attributes for the netCDF output files.
# Any number of attributes can be specified here; when not specified,
# the title is copied from generalSettings.
[netCDFAttributes]
institution= Department Physical Geography, Utrecht University
            description= Default simulation with PCR-GLOBWB V1.0 for the year 2000

# netCDFDimensions: standard dimension names of netCDF files have to be
# specified here. They include a timeDimension, xCoordinateDimension and
# yCoordinateDimension. Values for the spatial dimensions are copied from
# the clone map, temporal values are created from the model run dates.
# These names are used to generate netCDF output but also as default to
# read input netCDF files when no dimensions are specified.
# Please note that per (sub)section only one set of time/space coordinates
# can be defined.
[netCDFDimensions]
xCoordinateDimension= Longitude
yCoordinateDimension= Latitude
timeDimension= time

# mapSettings: specifies the location and fileName of the area of interest (clone),
# the cell area and the fraction fresh surface water;
# this can be a map in the native PCRaster format or a netCDF field with only
# x-y dimensions (e.g., lon-lat) with the smallest possible extent (cf.
# resample -C ... in the PCRaster manual). Cells outside the area of interest
# should contain missing values or set to False.
# cloneMap            :  clone map, netCDF identified by '.nc' extension,
#                 :  map attributes are taken from this map.
# cellArea            :  cell area of the land mass, including freshwater
#                  surface area in each cell (m2)
# localInputDirectory   :  optional input location, absolute or relative,
#                  which can be specified in most input locations;
```

```
#                     alternatively, map name can be specified with
#                     full absolute or relative path.
# Note that all variables are specified here using relative paths.
[mapSettings]
cloneMap= mask_M33.map #NH aanpassen
cellArea= LatinAmerica_Cellarea_05min.map

# meteoSettings: specifies the meteorological forcing used to run the model.
# At present, there are no general settings related to this section other than:
# localInputDirectory    :  optional input location, absolute or relative,
#                     which can be specified in most input locations;
#                     alternatively, map name can be specified with
#                     full absolute or relative path.
#
# Forcing includes the following compulsory variables with said dimensions
# that have to be specified as subsections with the following variables:
# precipitation         :  precipitation total (m/day per unit area)
# airTemperature        :  average temperature (degC)
# referencePotentialEvapotranspiration
#                   :  reference potential evapotranspiration
#                     (m/day per unit area)
#
# Forcing includes the following optional variables with said dimensions;
# these concern climate anomalies using the delta method that default to
# no change when not specified; when required, they have to be specified
# as subsections  with the following variables:
# precipitationAnomaly    :  precipitation multiplicative anomaly, dP (-),
#                     such that P_ch= dP*P_orig;
# airTemperatureAnomaly   :  temperature additive anomaly, dT (degC),
#                     such that T_ch= T_orig+dT;
# referencePotentialEvapotranspirationAnomaly
#                   :  reference potential evapotranspiration
#                     multiplicative anomaly, dE (-), such that
#                     E_ch= dE*E_orig.
#
# Each subSection takes the following input:
# input              :  value or string referring to the relative or
#                     absolute path of the input file. This input file
#                     can be the file root of a map stack in the native
#                     PCRaster format where argument substitution is
#                     used to identify individual years. Alternatively,
#                     it can refer to a netCDF file holding fields with
#                     the temporal resolution specified.
# variableName          :  variable name; in the case of existing PCRaster
#                     input, this is a dummy name; in the case of netCDF
#                     input, this is supposed to be the variable name
#                     under which relevant fields are stored in a file.
# conversionFactors      :  conversionFactors that can be specified to convert
#                     input that does not have the correct units
#                                                                  to the desired units listed above.
#                     Conversion takes the form y= a+bx and the values
#                     are specified as a pair (e.g.,
#                     conversionFactors= -273.15, 1 will convert
#                     temperature in units of K to degC). Note that the
#                     conversion factors reverts to 0, 1  when not
#                     specified (no conversion).
# xCoordinateDimension, yCoordinateDimension,
# timeDimension         :  optional dimensions to identify time and spatial
#                     coordinates in netCDF files. If not specified
#                     the names listed under netCDFDimensions will be
#                     used by default. Any names specified here are
#                     without consequence in the case PCRaster input
#                     is used.
# For example, inputFileName= meteo%04d/ra000000.001 will assume that all
# meteo input for each year is stored in a separate folder (e.g., meteo2000
# for the year 2000) and that for any or every time step a meteo field exists in
# with PCRaster format with the name ra000000.001, ra000000.002 etc. In contrast,
# GLOBAL_NCEP_Meteo_1948-2000_2d5deg.nc can refer to a netCDF file holding
# all relevant meteo input on a regular 2.5 arc degree resolution globally
# where all relevant variables are identified by their name (e.g., prate)
# and converted using a conversion factor (rates from kg/m2/s to m/m2/day)
# and resampling it automatically to the extent of the clone map.
[meteoSettings]
# this takes no input but the relevant subsections;
# as an example a dummy temperature change of 0 degC is specified;
# this and all other anomalies default to zero when not given.
# The local input directory here refers to a relative path
#localInputDirectory= maps
[precipitation]
#-read precipitation from the original NCEP-NCAR file regridded to 0.5
# arc degrees globally. Precipitation is given as a rate (kg/m2/s) and has
# to be multiplied by 86400 seconds per day over 1000 kg/m3 to obtain
```

```
# the equivalent waterslice per day.
#input= ncep_ncar_1996_2000_prate.nc
input= crucorrected_era-combined_precipitation.nc
variableName= prate
#conversionFactors= 0., 86.4
timeDimension= time
yCoordinateDimension= lat
xCoordinateDimension= lon

[airTemperature]
#-read air temperature from the NCC dataset which has a grid resolution of
# 1 arc degree and specifies the variable air in units of K
#input= ncc_mean_daily_2m_temp_1996-2000.nc
input= crucorrected_era-combined_temperature.nc
variableName= air
#conversionFactors= -273.15, 1.0
timeDimension= time
yCoordinateDimension= lat
xCoordinateDimension= lon

[airTemperatureAnomaly]
input= 0.0

[referencePotentialEvapotranspiration]
#-reference potential evapotranspiration is read from ERA-INTERIM based
# computations with Penman-Monteith on a monthly scaled and downscaled to
# daily values applying Hamon's method to CRU TS 2.1 daily temperatures.
# Spatial resolution is 0.5 arc degrees globally, with units of m/day, hence
# no correction is required.
#input= crucor_era-interim_1996-2000_potentialReferenceEvapotranspiration.nc
input= crucorrected_era-combined_evapotranspiration.nc
variableName= evapotranspiration
timeDimension= time
yCoordinateDimension= latitude
xCoordinateDimension= longitude

# landCoverSettings: specifies the information for each land cover type
# listed under globalSettings and subsections for their default settings:
# defaultSnowSettings, defaultVegetationSettings and defaultSnowSettings.
# General settings related to landCoverSettings include the local input
# directory only. Default settings are assigned to all land cover types
# if no specific values are provided under the respective subsections.
# If present, specific values take precedence over the default ones.
# Under landCoverSettings there are presently no general settings other than:
# localInputDirectory    : optional input location, absolute or relative,
#                  which can be specified in most input locations;
#                  alternatively, map name can be specfied with
#                  full absolute or relative path.
# alternativeStartDate   : an alternative start date in datetime formate
#                  to select initial settings from netCDF files
#                  (e.g., 1901-01-01 06:00:00)
[landCoverSettings]
# No input is provided here but the local input directory
# localInputDirectory= landuse_%04d  #Example

# defaultSnowSettings: specifies the default settings of the snow module
# of each land cover type. It includes the following variables:
# snowFallCorrectionFactor:   factor (-; 1.0 no change) that corrects for any
#                  snow undercatch
# thresholdTemperature   : threshold temperature, TT (degC), below which
#                  precipitation falls as snow, as rain above it
# temperatureMeltRate    : temperature dependent melt rate at which snow
#                  melts for any degC that T > TT (m/day/degC)
# snowWaterHoldingCapacity:   water holding capacity of snow cover, fraction
#                  of snow water equivalent
# refreezingCoeficient   : coefficient describing the fraction of liquid
#                  water held by the snow pack that refreezes when
#                  T < TT
# All values are entered here as scalars
[defaultSnowSettings]
snowFallCorrectionFactor= 1.0
thresholdTemperature= 0.0
temperatureMeltRate= 0.0025
snowWaterHoldingCapacity= 0.1
refreezingCoeficient= 0.05

# defaultVegetationSettings: specifies the default settings that pertain
# to the vegetation aspects of each land cover type. It includes the
# following variables:
# cropCoefficient        : scaling factor (crop coefficient) used to obtain
#                  the landcover-specific potential
#                  evapotranspiration (-)
```

```
# minCropCoefficient     :  minimum crop coefficient used to partition
#                           the landcover-specific potential
#                           evapotranspiration into bare soil evaporation
#                           and transpiration (-)
# coverFraction          :  fractional vegetation cover (-)
# interceptionCapacity   :  maximum interception capacity (m per unit area)
#
# Here only the default value of the minimum crop coefficient is set
[defaultVegetationSettings]
minCropCoefficient= 0.20

# defaultSlopeSettings: specifies the default settings for a characteristic slope
# which may comprise the following variables:
# slopeLength            :  length of the characteristic hill slope (m)
# slopeGradient          :  gradient of the characteristic hill slope (m/m)
# Here file names including the path are used
[defaultSlopeSettings] # added RvB
slopeLength= LatinAmerica_HYDRO1K_SlopeLength_30min.map
slopeGradient= LatinAmerica_GTOPO_SlopeGradient_30min.map

# defaultSoilSettings: specifies the default soil settings which may comprise:
# fieldCapacitySuction   :  matric suction corresponding to field capacity (m)
# redTranspirationSuction :  matric suction at which the actual transpiration
#                           reduces to half the potential amount (m);
#                           suctions are positive by definition and the field
#                           capacity should be larger than that at which
#                           the transpiration is halved
# swrcFactor,            :  factor and constant (-) in the unsaturated
# swrcConstant              hydraulic conductivity equation of Campbell (1974)
#                           of the form krel(Se)= Se^(f*beta+c) where Se is the
#                           relative degree of saturation, krel the relative
#                           unsaturated hydraulic conductivity and beta the
#                           shape factor of the soil water retention curve
#                           (SWRC) of Clapp & Hornberger (1978; comparable to
#                           Brooks & Corey, 1964). Originally, swrcFactor= 2
#                           and swrcConstant= 3
# soilThicknessLayer1, soilThicknessLayer2
#                        :  thickness (m) of the first (top) and second soil
#                           layer of the model
# thetaSatLayer1, thetaSatLayer2
#                        :  saturated volumetric moisture content (m3/m3)
#                           for the first (top) and second layer of the model
# thetaResLayer1, thetaResLayer2
#                        :  residual volumetric moisture content (m3/m3)
#                           for the first (top) and second layer of the model
# swrcAirEntryLayer1, swrcAirEntryLayer2
#                        :  air entry value (m) for the first (top) and second
#                           layer of the model according to the SWRC of
#                           Clapp & Hornberger (1978)
# swrcShapeFactorLayer1, swrcShapeFactorLayer2
#                        :  shape factor (beta, -) for the first (top) and
#                           second soil layer of the model according to the
#                           SWRC of Clapp & Hornberger (1978)
# kSatLayer1, kSatLayer2  :  saturated hydraulic conductivity (m/day) for the
#                           first (top) and second soil layer of the model
# rootFractionLayer1, rootFractionLayer2
#                        :  fraction of total root volume (-) present in the
#                           first (top) and second soil layer of the model
# minWHCRatio            :  ratio relating the minimum water holding capacity
#                           of the soil to the average water holding capacity
#                           which is computed on the basis of soil depth and
#                           maximum available pore space; used in the improved
#                           Arno scheme (Todini, 1996; Hagemann & Gates, 2003)
# arnoShapeFactor        :  the shape factor describing the distribution of
#                           water holding capacity mentioned here above.
# impededPercolationFraction
#                        :  fractional area (m2/m2) of the soil surface where
#                           percolation to the groundwater store is impeded
# Here all soil properties except root fractions and the parameters
# of the Arno scheme are set to default values. General properties are set
# as scalars, the others as maps
[defaultSoilSettings]
fieldCapacitySuction= 1.00
redTranspirationSuction= 3.33
swrcFactor= 2
swrcConstant= 3
soilThicknessLayer1= LatinAmerica_DSMW_SoilDepth-TopLayer_05min.map #was Global_FAO_Z_TopLayer_30min.map
soilThicknessLayer2= LatinAmerica_DSMW_SoilDepth-BottomLayer_05min.map #was Global_FAO_Z_BottomLayer_30min.map
thetaSatLayer1= LatinAmerica_DSMW_ThetaSat-TopLayer_05min.map #was Global_FAO_ThetaSat_TopLayer_30min.map
thetaSatLayer2= LatinAmerica_DSMW_ThetaSat-BottomLayer_05min.map #was Global_FAO_ThetaSat_BottomLayer_30min.map
thetaResLayer1= LatinAmerica_DSMW_ThetaRes-TopLayer_05min.map #was Global_FAO_ThetaRes_TopLayer_30min.map
thetaResLayer2= LatinAmerica_DSMW_ThetaRes-BottomLayer_05min.map #was Global_FAO_ThetaRes_BottomLayer_30min.map
```

swrcAirEntryLayer1= LatinAmerica_DSMW_AirEntryValue-TopLayer_05min.map #was Global_FAO_PsiAir_TopLayer_30min.map
swrcAirEntryLayer2= LatinAmerica_DSMW_AirEntryValue-BottomLayer_05min.map #was Global_FAO_PsiAir_BottomLayer_30min.map
swrcShapeFactorLayer1= LatinAmerica_DSMW_ShapeFactor-TopLayer_05min.map #was Global_FAO_Beta_TopLayer_30min.map
swrcShapeFactorLayer2= LatinAmerica_DSMW_ShapeFactor-BottomLayer_05min.map #was Global_FAO_Beta_BottomLayer_30min.map
kSatLayer1= LatinAmerica_DSMW_SatHydConduct-TopLayer_05min.map #was Global_FAO_KSat_TopLayer_30min.map
kSatLayer2= LatinAmerica_DSMW_SatHydConduct-BottomLayer_05min.map #was Global_FAO_KSat_BottomLayer_30min.map
impededPercolationFraction= LatinAmerica_DSMW_ImpededDrainage-ALL_05min.map #was Global_FAO_ImpededPercolation_30min.map

```
# landCoverTypeSettings: this pertains to the land cover types
# listed under globalSettings for which each a subsection has to be
# defined. In addition to any input to substitute the default values,
# this should at least include the following:
# shortName            :  short name used as an identifier, e.g.,
#                         a unique two letter code
# vegetationFraction     :  vegetation fraction (m2/m2) for each land cover
#                         type, all types summing to unity
# initial settings for the following variables; input can refer to
# a single value, a PCRaster map -as stored in the directory of initial states-
# or a netCDF file generated by the model;
# in the case of netCDF files, it is assumed that the initial states are
# coming from the time step preceding the start date but it is possible to
# define a single alternative start date. Initial settings include:
# interception              :  interception storage (m per unit area)
# snowSolidWaterContent        :  solid snow pack, water equivalent (m per unit area)
# snowLiquidWaterContent       :  liquid water in snow pack, (m per unit area)
# soilWaterContent_TopLayer, soilWaterContent_BottomLayer
#                          :  soil water storage, available as total and per layer
#                             (m per unit area)
# saturatedFraction          :  saturated surface fraction
# interFlow                 :  interflow from soil (m/day per unit area)
#
# Here all initial settings are set to zero. Root fractions and
# the parameters of the Arno scheme are set to the corresponding maps
[shortVegetation]
shortName= sv
vegetationFraction= LatinAmerica_GLCC_ShortVegetation_vegetationFraction_05min.map #was 0.666
rootFractionLayer1= LatinAmerica_GLCC_ShortVegetation_rootFraction-TopLayer_05min.map #was
Global_GLCC_RootFraction_ShortVegetation_TopLayer_30min.map
rootFractionLayer2= LatinAmerica_GLCC_ShortVegetation_rootFraction-BottomLayer_05min.map #was
Global_GLCC_RootFraction_ShortVegetation_BottomLayer_30min.map
minWHCRatio= LatinAmerica_GLCC_ShortVegetation_minWHCRatio_05min.map #was Global_GLCC_MinWHC_TopLayer_ShortVegetation_30min.map
arnoShapeFactor= LatinAmerica_GLCC_ShortVegetation_arnoShapeFactor_05min.map #was
Global_GLCC_ArnoShapeFactor_ShortVegetation_30min.map
cropCoefficient= kc_s #cleaned this to file roots RvB
coverFraction= cv_s  #cleaned this to file roots RvB
interceptionCapacity= smax_s  #cleaned this to file roots RvB
interception= 0.0  #it is good to include here and for the following the outcome of the test run for the actual run as a first estimate of the warm state RvB
snowSolidWaterContent= 0.0
snowLiquidWaterContent= 0.0
soilWaterContent_TopLayer= 0.0
soilWaterContent_BottomLayer= 0.0
saturatedFraction= 0.0
interFlow= 0.0

[tallVegetation]
shortName= tv
vegetationFraction= LatinAmerica_GLCC_TallVegetation_vegetationFraction_05min.map #was 0.334
rootFractionLayer1= LatinAmerica_GLCC_TallVegetation_rootFraction-TopLayer_05min.map #was
Global_GLCC_RootFraction_TallVegetation_TopLayer_30min.map
rootFractionLayer2= LatinAmerica_GLCC_TallVegetation_rootFraction-BottomLayer_05min.map #was
Global_GLCC_RootFraction_TallVegetation_BottomLayer_30min.map
minWHCRatio= LatinAmerica_GLCC_TallVegetation_minWHCRatio_05min.map #was Global_GLCC_MinWHC_TopLayer_TallVegetation_30min.map
arnoShapeFactor= LatinAmerica_GLCC_TallVegetation_arnoShapeFactor_05min.map #was Global_GLCC_ArnoShapeFactor_TallVegetation_30min.map
cropCoefficient= kc_t #cleaned this to file roots RvB
coverFraction= cv_t #cleaned this to file roots RvB
interceptionCapacity= smax_t #cleaned this to file roots RvB
interception= 0.0 #it is good to include here and for the following the outcome of the test run for the actual run as a first estimate of the warm state RvB
snowSolidWaterContent= 0.0
snowLiquidWaterContent= 0.0
soilWaterContent_TopLayer= 0.0
soilWaterContent_BottomLayer= 0.0
saturatedFraction= 0.0
interFlow= 0.0

# groundwaterSettings: specifies the input for the groundwater part of the model.
# This includes the groundwater recession coefficient and the initial
# groundwater storage.
# recessionCoefficient    :  groundwater recession coefficient (1/days)
# specificYield          :  groundwater specific yield (m/m)
# groundwaterInfluenceDepth:   depth influenced by capillary rise (m)
# relativeElevation       :  relative elevation of the foodplain (m);
#                          requires 12 percentile values including
```

```
#                       1, 5, 10, 20 ... 100%; can be provided as the
#                       root of PCRaster map or a netCDF file with the
#                       percentiles included as a separate dimension.
# initial settings for the following variables; input can refer to
# a single value, a PCRaster map -as stored in the directory of initial states-
# or a netCDF file generated by the model;
# groundwaterStorage      :  initial groundwater storage (m per unit area)
#
# As an example the optional localInputDirectory is specified and all
# files are located relative to this path. In this case, this is relative
# to the inputRootDirectory, e.g., ./maps/global_slopelength_30min.map;
# relative elevation is described by maps with the file root global_dzrel_30min
# and the percentiles included as extension, e.g., global_dzrel_30min.001 for
# the first 1% interval. In the case of netCDF a percentileDimension and
# variableName has to be specified.
[groundwaterSettings]
#localInputDirectory= maps
recessionCoefficient= LatinAmerica_GroundWaterRecessionCoefficient_05min.map #was Global_GroundWaterAlpha_30min.map
specificYield= LatinAmerica_GroundWaterSpecificYield_05min.map #added RvB
capillaryRiseInfluenceDepth= 5.0
relativeElevation= LatinAmerica_Hydro1k_dzrel_%04_05min.map #LatinAmerica_Hydro1k_dzrel_0100_05min.map #was global_dzrel_30min.%03d
groundwaterStorage= 0.0

# surfacewaterSettings: specifies the characteristics of the surface water
# network, including the those of channels, lakes and reservoirs that define
# the routing of the floodwave.
# Compulsory variables include:
# includeRouting         :  includes the routing component in the simulation,
#                       to be set to True or False
# localDrainageNetwork    :  local drainage direction map in PCRaster format
# fractionWater          :  fraction of the land mass in each cell occupied
#                       by surface freshwater (m2/m2)
# cropCoefficient        :  scaling factor (crop coefficient) for reference
#                       potential evapotranspiration over open water (-)
#                       potential open water evaporation.
#
# If the routing component is run, the following additional variables have to
# be specified:
# channelGradient        :  gradient along the drainage network (m/m)
# channelWidth           :  width of a characteristic rectangular channel (m)
# channelDepth           :  depth of a characteristic rectangular channel (m)
# manningCoefficient     :  manning coefficient for the channel
# waterBodyID            :  map identifying contiguous water bodies by a
#                       unique ID
# waterBodyType          :  map representing the corresponding waterbody type;
#                       0: channels; 1: lakes; 2: reservoirs.
# waterBodyOutlet        :  map identifying a single outlet from lakes and
#                       reservoirs by their corresponding ID. Endorheic
#                       lakes have no outlet specified. Note that the
#                       outlets have to be positioned in a way that the
#                       local drainage direction map remains sound.
# reservoirCapacity      :  map with the total storage capacity of each
#                       identified reservoir (m3)
# maxReservoirStorageRatio:  ratio (-) relating the maximum storage level
#                       under normal reservoir operation to total storage
# minReservoirStorageRatio:  ratio (-) relating the minimum storage level
#                       under normal reservoir operation to total storage
# resevoirDemand         :  map of potential reservoir demand (m3/s) at the
#                       outlet of each reservoir; if not specified, the
#                       reservoir operation reverts to one of constant
#                       release
# initial settings for the following variables have to be specified
# if routing is included; input can refer to a single value, a PCRaster map
# -as stored in the directory of initial states- or a netCDF file generated by the model;
# discharge              :  discharge along drainage network (m3/s)
# waterStorage           :  active water storage (m3)
#
# As an example, relative paths are used here
[surfacewatertSettings]
includeRouting= True #was False
localDrainageNetwork= ldd_latinamerica_5min.map #was maps/Global_LDD_30min.map
fractionWater= LatinAmerica_FractionWater_05min.map #was maps/Global_FractionWater_30min.map
cropCoefficient= 1 #was maps/kc_wat #RvB: Dit is wat lastiger omdat het van het type waterlichaam afhangt. Ik kan de kaarten maken maar zet de
waarde voorlopig op 1 (openwaterverdamping gelijk aan referentieverdamping)
channelGradient= LatinAmerica_Hydro1k_ChannelGradient_05min.map #was Global_ChannelGradient_30min.map
channelWidth= LatinAmerica_ChannelWidth_05min.map #was Global_ChannelWidth_30min.map
channelDepth= LatinAmerica_ChannelDepth_05min.map #was Global_ChannelDepth_30min.map
manningCoefficient= 0.04
waterBodyID= LatinAmerica_GRAND_WaterBodiesID_05min.map #was Global_GLWD_WaterBodiesID_30min.map
waterBodyType= LatinAmerica_GRAND_WaterBodiesType_05min.map #was Global_GLWD_WaterBodiesType_30min.map
waterBodyOutlet= LatinAmerica_GRAND_WaterBodiesOutlet_05min.map #was Global_GLWD_WaterBodiesOutlet_30min.map
reservoirCapacity= LatinAmerica_GRAND_ReservoirCapacity_05min.map #was Global_GLWD_ReservoirCapacity_30min.map
```

```
maxReservoirStorageRatio= 0.75
minReservoirStorageRatio= 0.10
reservoirDemand= 0.0
discharge= 0.0
waterStorage= 0.0

# outputSettings: specifies which output products are kept or permanently written
# to disk. Possible outputs include values, averages and totals at daily,
# monthly and yearly intervals and are included by means of te following
# variables:
# dailyValues       : daily output to be preserved
# monthlyValues     : daily output preserved at the end of each month
# yearlyValues      : daily output preserved at the end of each year;
#                   those variables required for initial conditions
#                   are written by default
# monthlyAverage    : output of the average daily values over each month
# yearlyAverage     : output of the average daily values over each year
# monthlyStDev      : standard deviation of the daily values per month
# yearlyStDev       : standard deviation of the daily values per year
# monthlyTotal      : output of the total of daily values over the month
# yearlyTotal       : output of the total of daily values over the year
#
# Values can be reported aggregated over the land surface in the cell or for
# each land cover type. Layer output is listed by the suffix Bottom, resp.
# Top to the name. Land cover specific output can be identified by adding
# the argument substitution string '_%s' to the variable name; without this
# only the aggregated value will be written. For example:
# monthlyTot= actualTranspiration_BottomLayer_%s
# will create actualTranspiration_BottomLayer_TallVegetation_monthlyTotal.nc and
# actualTranspiration_BottomLayer_ShortVegetation_monthlyTotal.nc,
# the file that holds the monthly totals of the actual transpiration for tall
# vegetation withdrawn from the model's bottom layer (second store).
#
# For each land cover class and aggregated over the land surface,
# the reportable variables include:
# precipitation          : precipitation (m/day per unit area)
# temperature            : air temperature (degC per unit area)
# potentialEvaporation   : potential evapotranspiration (m/day per unit area)
# potentialBareSoilEvaporation : potential bare soil evaporation (m/day per unit area)
# potentialTranspiration : potential transpiration, available as total and per layer
# actualEvaporation      : actual evapotranspiration (m/day per unit area)
# actualBareSoilEvaporation : actual bare soil evaporation (m/day per unit area)
# actualTranspiration    : actual transpiration, available as total and per layer
# interception           : interception storage (m per unit area)
# snowSolidWaterContent  : solid snow pack, water equivalent (m per unit area)
# snowLiquidWaterContent : liquid water in snow pack, (m per unit area)
# soilWaterContent       : soil water storage, available as total and per layer
#                        (m per unit area)
# soilWaterFraction      : soil volumetric water content (m/m per unit area)
# saturatedFraction      : saturated surface fraction
# shallowGroundWaterFraction : fraction of land surface influenced by capillary rise
#
# directRunoff           : surface runoff from the saturated fraction or
#                        infiltration excess (m/day per unit area)
# interFlow              : interflow from soil (m/day per unit area)
# baseFlow               : base flow from groundwater store (m/day per unit area)
# specificRunoff         : specific runoff from the soil area only
#                        (sum of direct runoff, interflow and baseflow; m/day
#                        per unit area)
# Over the land surface, the reportable variables include:
# groundwaterStorage     : groundwater storage (m per unit area)
# groundwaterRecharge    : groundwater recharge (m/day per unit area)
# discharge              : discharge along drainage network (m3/s)
# waterStorage           : active water storage (m3)
# waterDepth                                      :          water depth
[outputSettings]
#dailyValues= discharge
#monthlyValues= groundwaterStorage
#yearlyValues= snowSolidWaterContent, snowLiquidWaterContent, waterStorage
#monthlyAverage= discharge, soilWaterFraction_%s, saturatedFraction_%s
#yearlyAverage= discharge, groundwaterRecharge
#monthlyStDev= discharge, groundwaterRecharge
#yearlyStDev= discharge, groundwaterRecharge
#monthlyTotal= precipitation, potentialTranspiration, actualTranspiration,\
# directRunoff, actualTranspiration_%s, actualTranspiration_TopLayer_%s,\
# actualTranspiration_BottomLayer_%s
#yearlyTotal= precipitation
monthlyAverage= temperature, soilWaterContent, groundwaterRecharge, waterStorage, discharge,\
        groundwaterStorage, groundwaterRecharge
monthlyTotals= precipitation, potentialBareSoilEvaporation, potentialTranspiration,\
        actualBareSoilEvaporation, actualTranspiration
```

```
#####################################################################################
# End of the configuration file ###################################################
#####################################################################################
```

1.8.1 Scripts and tools for pre- and post-processing data for the PCRGLOBWB model

The scripts in the table below are Python (2.7) scripts.
Some scripts are stand-alone scripts the can be run from the command line.
Some scripts are written to use in ArcGIS as stand-alone script of as (part of a) geoprocessing model.

Name	Functionality	Remarks	Arguments
InputGLOBWB_discreet_ Resample_ Raster2map.py	Convert input PCRaster maps to ArcGIS feature class in geodatabase using GDAL Specifies coordinate system (WGS84) Resample cell size of rasters from 0.5 degr cell size to 30 arcsecs, using nearest neighbourhood resampling for discrete input variables Extracts rasters to case study mask areas Saves maps in PCRaster format and under correct names for PCRGLOBWB model	Requires GDAL 1.8 or higher for conversion between PCRaster and ArcGIS formats	The script can be executed from the command line and needs 5 arguments: - Input directory - Data type (discreet or continuous) - a raster file or dataset (as mask file) - fGDB[2] where the results will be stored - Output directory
InputGLOBWB_continuous_ Resample_Raster2map.py	Convert input PCRaster maps to ArcGIS feature class in geodatabase using GDAL Specifies coordinate system (WGS84) Resample cell size of rasters from 0.5 degr cell size to 30 arcsecs, - using the bilinear resampling method for input variables that are fractions. - For continuous variables is the cubic convolution Extracts rasters to masks*[3] of the case study areas Saves maps in PCRaster format and under correct names for PCRGLOBWB model	Requires GDAL 1.8 or higher for conversion between PCRaster and ArcGIS formats	The script can be executed from the command line and needs 4 arguments: - Input directory - Data type (discreet or continuous) - a raster file or dataset (as mask file) - fGDB where the result rasters are put\stored.
PolyFeatureFields2PCrasterFile s_ rs.py	Input: polygon dataset of land cover with 74 land cover variables in the attribute table Creates raster datasets of the 74 land cover variables at the masks of the case study areas Converts the raster datasets to PCRaster maps for input into PCRGLOBWB and assigns the correct names to the PCRaster input maps	Requires GDAL 1.8 or higher for conversion between PCRaster and ArcGIS formats	This script can be executed in ArcGIS. It needs 4 arguments: - the input feature class - a raster dataset (serve as snapraster and (cell size) mask - a fGDB (for intermediate files) - the folder where the output files will be written to)
WarmingUpPCRGLOBWB.py	Initialises the PCRGLOBWB model by running the model 100 times based on a set of initial input maps and input climatic maps for one selected year Returns a set of initial input maps to run the PCRGLOBWB model for a series of years	Set correct name of PCRGLOBWB script and correct numbers of input ini files and generated ini files	The script can be run at the command line and needs 1 argument: - warming-up year (yyyy)
BatchPCRGLOBWB_2.py and	Runs the PCRGLOBWB model for a series of years Stores results in one zipfile for each year Prevents the 3rd store from becoming <0 after each year Mexico - Takes into account dams and dam releases by copying the damrelease map into the folder with the (static) maps used as input for the PCRGLOBWB model.	Set correct name of PCRGLOBWB script and correct numbers of input ini files	The scripts can be executed from the command line and needs 3 arguments: - the first or start year (yyyy) - the last year - the PCRGLOBWB model script file (name) .
BatchPCRGLOBWB_2_Mexico. py	Runs the PCRGLOBWB model for a series of years Stores results in one zipfile for each year Prevents the 3rd store from becoming <0 after each year Includes provisions for inflow from reservoir at river basin boundary (specifically created for Mexican study area)	Specific for the Mexican case study area; Not delivered for the general DSS.	The scripts can be executed from the command line and needs 3 arguments: - the first or start year (yyyy) - the last year - the name of the PCRaster model script file .

[2] fGDB = (ArcGis) file geodatabase

[3] The masks were the: raster dataset of the case study area with cell size of 30 arcsecs, and coordinate system WGS84

Name	Functionality	Remarks	Arguments
DrainageStatisticsPerMonth.py DrainageStatisticsPerSeason.py	Generate Cell Statistics (per month of per season) of (daily) rasters ordered per year.		The scripts can be run at\ executed from the command line and needs 1 argument: - The folder (or workspace) containing the rasters.
ExtractManyRastersByMask.py	To extract the case study site part from raster files with larger extent.		This script can be executed in ArcGIS. It needs 4 arguments: - the folder or workspace (fGDB) containing the larger rasters - Mask raster dataset - a fGDB where the result rasters are stored - a text variable (used to create an new output file name)
Files2fGDB.py Files2fGDB_LA.py Files2fGDB_Results.py Files2fGDB_WSI_input.py Files2fGDB_WSI_output.py	To convert PCRaster files to rasters or features stored in fGDB's. The different between the scripts are related to the type of input files and\or the renaming of the files.		The scripts can be run at\ executed from the command line and needs 2 arguments: - The source directory path containing the PCRaster files - The destination path (location of the fGDB).
ExtractFilesFromZip_2.py ExtractFilesFromZip_3.py	To extract PCRaster files from zip files and place them in the right folder.		The scripts can be run at\ executed from the command line and needs 2 arguments: - The path and filename of the zip containing the PCRaster files - The destination path (folder).
ASCII2floatraster.py	Converts ASCII (raster) files to raster datasets (in a fGDB)		This script can be executed in ArcGIS. It needs 2 arguments: - Input workspace (folder containing the ASCII files) - fGDB were the raster dataset will be stored

1.9 PCRaster Cartographic Modelling Scripts for the Water Demand and Water Stress Assessment Tools

1.9.1 Cartographic Modelling Scripts for water demand and water stress Argentina

```
# Cartographic modelling script file to calculate maps of water water withdrawal and water stress
# COROADO Project, Simone Verzandvoort, last revised 30 September 2014

#!--unitcell

binding

# General

# Mask of study area
AREA=maps\wsi\catclone.map;

# Digital elevation map
DEM=maps\wsi\adem.map;

# Slope gradient map
GRAD=maps\wsi\grad.map;

# Cell area (m2)
CELLAREA=maps\wsi\cellarea30.map;

# Settings for friction factors to water supply; distance as friction factor is default
# No specific settings required for friction based on distance and elevation difference to water supply points

# Water availability

# input: monthly averaged discharge maps for the period 2000-2010
qavg_jan=maps\wsi\mean01.map;
qavg_feb=maps\wsi\mean02.map;
qavg_mar=maps\wsi\mean03.map;
qavg_apr=maps\wsi\mean04.map;
qavg_may=maps\wsi\mean05.map;
qavg_jun=maps\wsi\mean06.map;
qavg_jul=maps\wsi\mean07.map;
qavg_aug=maps\wsi\mean08.map;
qavg_sep=maps\wsi\mean09.map;
qavg_oct=maps\wsi\mean10.map;
qavg_nov=maps\wsi\mean11.map;
qavg_dec=maps\wsi\mean12.map;

# input: monthly averaged required environmental flow; scaled from reported value of 1 m3.s-1 at San Roque station
QENV_JAN=maps\wsi\q_env001.map;
QENV_FEB=maps\wsi\q_env002.map;
QENV_MAR=maps\wsi\q_env003.map;
QENV_APR=maps\wsi\q_env004.map;
QENV_MAY=maps\wsi\q_env005.map;
QENV_JUN=maps\wsi\q_env006.map;
QENV_JUL=maps\wsi\q_env007.map;
QENV_AUG=maps\wsi\q_env008.map;
QENV_SEP=maps\wsi\q_env009.map;
QENV_OCT=maps\wsi\q_env010.map;
QENV_NOV=maps\wsi\q_env011.map;
QENV_DEC=maps\wsi\q_env012.map;

# Water demand (approximated by withdrawal)
# input: administrative and user zones

#SECTORS=maps\wsi\sectors.map;          #map of administrative units to express water demand; not applicable to Suquia River basin
#map with potential extractionpoints for all water uses: includes streams, canals and all user zones, since all users withdraw water from groundwater
#locations of extraction points not available for Suquia River Basin; used stream and channel network and user zones to determine available blue water
EXTRPOINTS=maps\wsi\all_extractionpointsID_nonmv.map;
URBAN_ZONES=maps\wsi\urban_zonesID.map;          #maps with urban, industrial, irrigated and mining zones
INDUSTR_ZONES=maps\wsi\industr_zonesID.map;
AGR_ZONES=maps\wsi\irrigation_zonesID.map;
#MINING_ZONES=maps\wsi\actualmining_zonesID.map;          # no mines in Suquia River Basin

# input: gross annual average water demand data in tables per sector, water type and user type (m3.s-1)
WATERDEMAND_SURFWAT_SECT_URBTBL=maps\wsi\waterdemand_surfwat_sectors_urban.tbl;     #table with water withdrawal from surface water for urban use
WATERDEMAND_GROUNDWAT_SECT_URBTBL=maps\wsi\waterdemand_groundwat_sectors_urban.tbl;     #table with water withdrawal from groundwater for urban use
WATERDEMAND_SURFWAT_SECT_INDTBL=maps\wsi\waterdemand_surfwat_sectors_industr.tbl;     #table with water withdrawal from surface water for industrial use
WATERDEMAND_GROUNDWAT_SECT_INDTBL=maps\wsi\waterdemand_groundwat_sectors_industr.tbl;     #table with water withdrawal from groundwater for industrial use
WATERDEMAND_SURFWAT_SECT_AGRTBL=maps\wsi\waterdemand_surfwat_sectors_agr.tbl;     #table with water withdrawal from surface water for agricultural use
```

WATERDEMAND_GROUNDWAT_SECT_AGRTBL=maps\wsi\waterdemand_groundwat_sectors_agr.tbl; #table with water withdrawal from groundwater for agricultural use
#WATERDEMAND_SURFWAT_SECT_MININGTBL=maps\wsi\waterdemand_surfwat_sectors_mining.tbl; #table with water withdrawal from surface water for mining
#WATERDEMAND_GROUNDWAT_SECT_MININGTBL=maps\wsi\waterdemand_groundwat_sectors_mining.tbl; #table with water withdrawal from groundwater for mining

# input: monthly proportion of irrigation water demand
AGR_PROP001TBL=maps\wsi\agr_prop001.tbl;
AGR_PROP002TBL=maps\wsi\agr_prop002.tbl;
AGR_PROP003TBL=maps\wsi\agr_prop003.tbl;
AGR_PROP004TBL=maps\wsi\agr_prop004.tbl;
AGR_PROP005TBL=maps\wsi\agr_prop005.tbl;
AGR_PROP006TBL=maps\wsi\agr_prop006.tbl;
AGR_PROP007TBL=maps\wsi\agr_prop007.tbl;
AGR_PROP008TBL=maps\wsi\agr_prop008.tbl;
AGR_PROP009TBL=maps\wsi\agr_prop009.tbl;
AGR_PROP010TBL=maps\wsi\agr_prop010.tbl;
AGR_PROP011TBL=maps\wsi\agr_prop011.tbl;
AGR_PROP012TBL=maps\wsi\agr_prop012.tbl;

Output

# Gross water demand maps (absolute: in m3.s-1 per year)
# Environmental demand is already defined above (QENV_month)
D_URBAN=results\wsi\D_urban.map;
D_INDUSTR=results\wsi\D_industr.map;
D_AGR=results\wsi\D_agr.map;

# Monthly water demand maps for irrigation (m3.s-1 per month)
D_AGR_001=results\wsi\D_agr0001.map;
D_AGR_002=results\wsi\D_agr0002.map;
D_AGR_003=results\wsi\D_agr0003.map;
D_AGR_004=results\wsi\D_agr0004.map;
D_AGR_005=results\wsi\D_agr0005.map;
D_AGR_006=results\wsi\D_agr0006.map;
D_AGR_007=results\wsi\D_agr0007.map;
D_AGR_008=results\wsi\D_agr0008.map;
D_AGR_009=results\wsi\D_agr0009.map;
D_AGR_010=results\wsi\D_agr0010.map;
D_AGR_011=results\wsi\D_agr0011.map;
D_AGR_012=results\wsi\D_agr0012.map;

#D_MINING=results\wsi\D_mining.map; # no mines in Suquia River Basin

Annual and monthly total water demand maps (from all sectors)

D_TOT=results\wsi\D_tot.map;

D_TOT_001=results\wsi\D_tot001.map;
D_TOT_002=results\wsi\D_tot002.map;
D_TOT_003=results\wsi\D_tot003.map;
D_TOT_004=results\wsi\D_tot004.map;
D_TOT_005=results\wsi\D_tot005.map;
D_TOT_006=results\wsi\D_tot006.map;
D_TOT_007=results\wsi\D_tot007.map;
D_TOT_008=results\wsi\D_tot008.map;
D_TOT_009=results\wsi\D_tot009.map;
D_TOT_010=results\wsi\D_tot010.map;
D_TOT_011=results\wsi\D_tot011.map;
D_TOT_012=results\wsi\D_tot012.map;

# Maps of local water withdrawal-to-availability ratio per month (-)
D_WA_001=results\wsi\D_wa001.map;
D_WA_002=results\wsi\D_wa002.map;
D_WA_003=results\wsi\D_wa003.map;
D_WA_004=results\wsi\D_wa004.map;
D_WA_005=results\wsi\D_wa005.map;
D_WA_006=results\wsi\D_wa006.map;
D_WA_007=results\wsi\D_wa007.map;
D_WA_008=results\wsi\D_wa008.map;
D_WA_009=results\wsi\D_wa009.map;
D_WA_010=results\wsi\D_wa010.map;
D_WA_011=results\wsi\D_wa011.map;
D_WA_012=results\wsi\D_wa012.map;

# Map of friction by distance
FRICDIST=results\wsi\fricdist.map;

# Water stress index maps based on friction by distance to water supply points (default)
WSI_001=results\wsi\wsi_001.map;
WSI_002=results\wsi\wsi_002.map;
WSI_003=results\wsi\wsi_003.map;
WSI_004=results\wsi\wsi_004.map;
WSI_005=results\wsi\wsi_005.map;
WSI_006=results\wsi\wsi_006.map;
WSI_007=results\wsi\wsi_007.map;

```
WSI_008=results\wsi\wsi_008.map;
WSI_009=results\wsi\wsi_009.map;
WSI_010=results\wsi\wsi_010.map;
WSI_011=results\wsi\wsi_011.map;
WSI_012=results\wsi\wsi_012.map;

initial
# calculation of water demand maps per administrative sector and/or in water user zones (m3.s-1 per year and per administrative sector or user zone)
# water demand from surface water and groundwater is calculated separately
# water demand satisfied from sources outside the catchment (e.g. desalinated or imported water) should be subtracted from water demand

WATERDEMAND_SURFWAT_URBAN=lookupscalar(WATERDEMAND_SURFWAT_SECT_URBTBL,URBAN_ZONES);
WATERDEMAND_GROUNDWAT_URBAN=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_URBTBL,URBAN_ZONES);
WATERDEMAND_URBAN_SECT=WATERDEMAND_SURFWAT_URBAN+WATERDEMAND_GROUNDWAT_URBAN;
report D_URBAN=cover(if(boolean(URBAN_ZONES),WATERDEMAND_URBAN_SECT),scalar(0));

WATERDEMAND_SURFWAT_INDUSTR=lookupscalar(WATERDEMAND_SURFWAT_SECT_INDTBL,INDUSTR_ZONES);
WATERDEMAND_GROUNDWAT_INDUSTR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_INDTBL,INDUSTR_ZONES);
WATERDEMAND_INDUSTR_SECT=WATERDEMAND_SURFWAT_INDUSTR+WATERDEMAND_GROUNDWAT_INDUSTR;
report D_INDUSTR=cover(if(boolean(INDUSTR_ZONES),WATERDEMAND_INDUSTR_SECT),scalar(0));

WATERDEMAND_SURFWAT_AGR=lookupscalar(WATERDEMAND_SURFWAT_SECT_AGRTBL,AGR_ZONES);
WATERDEMAND_GROUNDWAT_AGR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_AGRTBL,AGR_ZONES);
WATERDEMAND_AGR_SECT=WATERDEMAND_SURFWAT_AGR+WATERDEMAND_GROUNDWAT_AGR;
report D_AGR=cover(if(boolean(AGR_ZONES),WATERDEMAND_AGR_SECT),scalar(0));

# Water demand for irrigation specified per month
report D_AGR_001=cover(lookupscalar(AGR_PROP001TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_002=cover(lookupscalar(AGR_PROP002TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_003=cover(lookupscalar(AGR_PROP003TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_004=cover(lookupscalar(AGR_PROP004TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_005=cover(lookupscalar(AGR_PROP005TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_006=cover(lookupscalar(AGR_PROP006TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_007=cover(lookupscalar(AGR_PROP007TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_008=cover(lookupscalar(AGR_PROP008TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_009=cover(lookupscalar(AGR_PROP009TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_010=cover(lookupscalar(AGR_PROP010TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_011=cover(lookupscalar(AGR_PROP011TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_012=cover(lookupscalar(AGR_PROP012TBL,AGR_ZONES)*D_AGR,scalar(0));

#WATERDEMAND_SURFWAT_MINING=lookupscalar(WATERDEMAND_SURFWAT_SECT_MININGTBL,SECTORS);
#WATERDEMAND_GROUNDWAT_MINING=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_MININGTBL,SECTORS);
#WATERDEMAND_MINING_SECT=WATERDEMAND_SURFWAT_MINING+WATERDEMAND_GROUNDWAT_MINING;
#report D_MINING=cover(if(boolean(MINING_ZONES),WATERDEMAND_MINING_SECT),scalar(0));

# Total gross water demand maps, per year and per month

report D_TOT=D_URBAN+D_INDUSTR+D_AGR;        #total gross water demand per year and per sector (m3.s-1); no mines in Suquia
#report D_TOT=D_URBAN+D_INDUSTR+D_AGR+D_MINING;        #total gross water demand per year and per sector (m3.s-1)

report D_TOT_001=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_001+QENV_JAN;
report D_TOT_002=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_002+QENV_FEB;
report D_TOT_003=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_003+QENV_MAR;
report D_TOT_004=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_004+QENV_APR;
report D_TOT_005=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_005+QENV_MAY;
report D_TOT_006=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_006+QENV_JUN;
report D_TOT_007=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_007+QENV_JUL;
report D_TOT_008=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_008+QENV_AUG;
report D_TOT_009=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_009+QENV_SEP;
report D_TOT_010=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_010+QENV_OCT;
report D_TOT_011=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_011+QENV_NOV;
report D_TOT_012=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_012+QENV_DEC;

# Local water withdrawal-to-availability ratio per month (-)
# Based on gross water water withdrawal; not accounting for return flows in absence of information on return flows and space-time distribuions

report D_WA_001=D_TOT_001/qavg_jan;
report D_WA_002=D_TOT_002/qavg_feb;
report D_WA_003=D_TOT_003/qavg_mar;
report D_WA_004=D_TOT_004/qavg_apr;
report D_WA_005=D_TOT_005/qavg_may;
report D_WA_006=D_TOT_006/qavg_jun;
report D_WA_007=D_TOT_007/qavg_jul;
report D_WA_008=D_TOT_008/qavg_aug;
report D_WA_009=D_TOT_009/qavg_sep;
report D_WA_010=D_TOT_010/qavg_oct;
report D_WA_011=D_TOT_011/qavg_nov;
report D_WA_012=D_TOT_012/qavg_dec;

# Maps of friction encountered on supply from water supply points to water user units
# FRICDIST: Friction imposed by distance (m)
# Cut-off at 1E-10 to prevent a 0 argument to the log-function for WSI calculation

CELLLENGTH=sqrt(CELLAREA);
report FRICDIST=max(1E-10,spread(EXTRPOINTS,0,1*CELLLENGTH));

# Water stress index per month based on friction-distance, local water withdrawal-to-availability ratio,
```

```
# and the absolute value of the water demand
# Log-transformation on WSI to obtain comprehensible values
report WSI_001=log10(FRICDIST*D_WA_001+1);
report WSI_002=log10(FRICDIST*D_WA_002+1);
report WSI_003=log10(FRICDIST*D_WA_003+1);
report WSI_004=log10(FRICDIST*D_WA_004+1);
report WSI_005=log10(FRICDIST*D_WA_005+1);
report WSI_006=log10(FRICDIST*D_WA_006+1);
report WSI_007=log10(FRICDIST*D_WA_007+1);
report WSI_008=log10(FRICDIST*D_WA_008+1);
report WSI_009=log10(FRICDIST*D_WA_009+1);
report WSI_010=log10(FRICDIST*D_WA_010+1);
report WSI_011=log10(FRICDIST*D_WA_011+1);
report WSI_012=log10(FRICDIST*D_WA_012+1);
```

1.9.2 Cartographic Modelling Scripts for water demand and water stress Brazil

```
# Cartographic modelling script file to calculate maps of water water withdrawal and water stress
# COROADO Project, Simone Verzandvoort, last revised 17 October 2014

#!--unitcell

binding

# General

# Mask of study area
AREA=maps\catclone.map;

# Digital elevation map
DEM=maps\Bdem.map;

# slope gradient map
GRAD=maps\grad.map;

# cell area (m2)
CELLAREA=maps\cellarea30.map;

# Settings for friction factors for water supply

# water quality standard map (proxy of actual water quality of water bodies and streams)
# 1 is highest required water quality, 4 lowest (scalar map type)
WATERQUALITYSTD=maps\wsi\waterqualitystandards.map;

# Water availability

# input: monthly averaged discharge maps for the period 2000-2010
# output from the PCRGLOBWB model
qavg_jan=maps\wsi\mean01.map;
qavg_feb=maps\wsi\mean02.map;
qavg_mar=maps\wsi\mean03.map;
qavg_apr=maps\wsi\mean04.map;
qavg_may=maps\wsi\mean05.map;
qavg_jun=maps\wsi\mean06.map;
qavg_jul=maps\wsi\mean07.map;
qavg_aug=maps\wsi\mean08.map;
qavg_sep=maps\wsi\mean09.map;
qavg_oct=maps\wsi\mean10.map;
qavg_nov=maps\wsi\mean11.map;
qavg_dec=maps\wsi\mean12.map;

# input: monthly averaged required environmental flow; not defined for Brazil
#QENV_JAN=maps\wsi\q_env001.map;
#QENV_FEB=maps\wsi\q_env002.map;
#QENV_MAR=maps\wsi\q_env003.map;
#QENV_APR=maps\wsi\q_env004.map;
#QENV_MAY=maps\wsi\q_env005.map;
#QENV_JUN=maps\wsi\q_env006.map;
#QENV_JUL=maps\wsi\q_env007.map;
#QENV_AUG=maps\wsi\q_env008.map;
#QENV_SEP=maps\wsi\q_env009.map;
#QENV_OCT=maps\wsi\q_env010.map;
#QENV_NOV=maps\wsi\q_env011.map;
#QENV_DEC=maps\wsi\q_env012.map;

# Water demand (approximated by withdrawal)

# input: administrative and user zones

#SECTORS=maps\wsi\sectors.map;			#map of administrative units to express water demand; not necessary for SPMR since water
demand data are input per water user zone
#map with potential extractionpoints for all water uses: includes streams, canals and all user zones, since all users withdraw water from groundwater
EXTRPOINTS=maps\wsi\all_extractionpointsID_nonmv.map;		#map with points of surface water extraction and points of groundwater extraction
URBAN_ZONES=maps\wsi\urban_zonesID.map;			#maps with urban, industrial, irrigated and mining zones
INDUSTR_ZONES=maps\wsi\industr_zonesID.map;
```

AGR_ZONES=maps\wsi\irrigation_zonesID.map;
#MINING_ZONES=maps\wsi\actualmining_zonesID.map; # mining areas indicated on land use map of SPMR, but no data on water demand available

# input: gross annual average water demand data in tables per sector, water type and user type (m3.s-1)
WATERDEMAND_SURFWAT_SECT_URBTBL=maps\wsi\waterdemand_surfwat_sectors_urban.tbl; #table with water withdrawal from surface water for urban use
WATERDEMAND_GROUNDWAT_SECT_URBTBL=maps\wsi\waterdemand_groundwat_sectors_urban.tbl; #table with water withdrawal from groundwater for urban use
WATERDEMAND_SURFWAT_SECT_INDTBL=maps\wsi\waterdemand_surfwat_sectors_industr.tbl; #table with water withdrawal from surface water for industrial use
WATERDEMAND_GROUNDWAT_SECT_INDTBL=maps\wsi\waterdemand_groundwat_sectors_industr.tbl; #table with water withdrawal from groundwater for industrial use
WATERDEMAND_SURFWAT_SECT_AGRTBL=maps\wsi\waterdemand_surfwat_sectors_agr.tbl; #table with water withdrawal from surface water for agricultural use
WATERDEMAND_GROUNDWAT_SECT_AGRTBL=maps\wsi\waterdemand_groundwat_sectors_agr.tbl; #table with water withdrawal from groundwater for agricultural use
#WATERDEMAND_SURFWAT_SECT_MININGTBL=maps\wsi\waterdemand_surfwat_sectors_mining.tbl; #table with water withdrawal from surface water for mining
#WATERDEMAND_GROUNDWAT_SECT_MININGTBL=maps\wsi\waterdemand_groundwat_sectors_mining.tbl; #table with water withdrawal from groundwater for mining

# input: monthly proportion of irrigation water demand
# source: USP, interview plenary meeting Cordoba, Nov 2013
AGR_PROP001TBL=maps\wsi\agr_prop001.tbl;
AGR_PROP002TBL=maps\wsi\agr_prop002.tbl;
AGR_PROP003TBL=maps\wsi\agr_prop003.tbl;
AGR_PROP004TBL=maps\wsi\agr_prop004.tbl;
AGR_PROP005TBL=maps\wsi\agr_prop005.tbl;
AGR_PROP006TBL=maps\wsi\agr_prop006.tbl;
AGR_PROP007TBL=maps\wsi\agr_prop007.tbl;
AGR_PROP008TBL=maps\wsi\agr_prop008.tbl;
AGR_PROP009TBL=maps\wsi\agr_prop009.tbl;
AGR_PROP010TBL=maps\wsi\agr_prop010.tbl;
AGR_PROP011TBL=maps\wsi\agr_prop011.tbl;
AGR_PROP012TBL=maps\wsi\agr_prop012.tbl;

Output

# Gross water demand maps (absolute: in m3.s-1 per year)
D_URBAN=results\wsi\D_urban.map;
D_INDUSTR=results\wsi\D_industr.map;
D_AGR=results\wsi\D_agr.map;

# Monthly water demand maps for irrigation (m3.s-1 per month)
D_AGR_001=results\wsi\D_agr0001.map;
D_AGR_002=results\wsi\D_agr0002.map;
D_AGR_003=results\wsi\D_agr0003.map;
D_AGR_004=results\wsi\D_agr0004.map;
D_AGR_005=results\wsi\D_agr0005.map;
D_AGR_006=results\wsi\D_agr0006.map;
D_AGR_007=results\wsi\D_agr0007.map;
D_AGR_008=results\wsi\D_agr0008.map;
D_AGR_009=results\wsi\D_agr0009.map;
D_AGR_010=results\wsi\D_agr0010.map;
D_AGR_011=results\wsi\D_agr0011.map;
D_AGR_012=results\wsi\D_agr0012.map;

#D_MINING=results\wsi\D_mining.map; # no information on water withdrawal for mining in SPMR

annual and monthly total water demand maps (from all sectors)

D_TOT=results\wsi\D_tot.map;

D_TOT_001=results\wsi\D_tot001.map;
D_TOT_002=results\wsi\D_tot002.map;
D_TOT_003=results\wsi\D_tot003.map;
D_TOT_004=results\wsi\D_tot004.map;
D_TOT_005=results\wsi\D_tot005.map;
D_TOT_006=results\wsi\D_tot006.map;
D_TOT_007=results\wsi\D_tot007.map;
D_TOT_008=results\wsi\D_tot008.map;
D_TOT_009=results\wsi\D_tot009.map;
D_TOT_010=results\wsi\D_tot010.map;
D_TOT_011=results\wsi\D_tot011.map;
D_TOT_012=results\wsi\D_tot012.map;

# maps of local water withdrawal-to-availability ratio per month (-)
D_WA_001=results\wsi\D_wa001.map;
D_WA_002=results\wsi\D_wa002.map;
D_WA_003=results\wsi\D_wa003.map;
D_WA_004=results\wsi\D_wa004.map;
D_WA_005=results\wsi\D_wa005.map;
D_WA_006=results\wsi\D_wa006.map;
D_WA_007=results\wsi\D_wa007.map;
D_WA_008=results\wsi\D_wa008.map;
D_WA_009=results\wsi\D_wa009.map;

```
D_WA_010=results\wsi\D_wa010.map;
D_WA_011=results\wsi\D_wa011.map;
D_WA_012=results\wsi\D_wa012.map;

# map of friction by distance
FRICDIST=results\wsi\fricdist.map;

# map of friction by legally required water quality of surface water bodies
FRICWQUAL=results\wsi\fricwqual.map;

# Water stress index maps based on friction by distance to water supply points (default)
WSI_001=results\wsi\wsi_001.map;
WSI_002=results\wsi\wsi_002.map;
WSI_003=results\wsi\wsi_003.map;
WSI_004=results\wsi\wsi_004.map;
WSI_005=results\wsi\wsi_005.map;
WSI_006=results\wsi\wsi_006.map;
WSI_007=results\wsi\wsi_007.map;
WSI_008=results\wsi\wsi_008.map;
WSI_009=results\wsi\wsi_009.map;
WSI_010=results\wsi\wsi_010.map;
WSI_011=results\wsi\wsi_011.map;
WSI_012=results\wsi\wsi_012.map;

# water stress index maps by required water quality standard
WSI_WQ_001=results\wsi\wsi_wq_001.map;
WSI_WQ_002=results\wsi\wsi_wq_002.map;
WSI_WQ_003=results\wsi\wsi_wq_003.map;
WSI_WQ_004=results\wsi\wsi_wq_004.map;
WSI_WQ_005=results\wsi\wsi_wq_005.map;
WSI_WQ_006=results\wsi\wsi_wq_006.map;
WSI_WQ_007=results\wsi\wsi_wq_007.map;
WSI_WQ_008=results\wsi\wsi_wq_008.map;
WSI_WQ_009=results\wsi\wsi_wq_009.map;
WSI_WQ_010=results\wsi\wsi_wq_010.map;
WSI_WQ_011=results\wsi\wsi_wq_011.map;
WSI_WQ_012=results\wsi\wsi_wq_012.map;


initial
# calculation of water demand maps per administrative sector and/or in water user zones (m3.s-1 per year and per administrative sector or user zone)
# water demand from surface water and groundwater is calculated separately
# water demand satisfied from sources outside the catchment (e.g. desalinated or imported water) should be subtracted from water demand

WATERDEMAND_SURFWAT_URBAN=lookupscalar(WATERDEMAND_SURFWAT_SECT_URBTBL,URBAN_ZONES);
WATERDEMAND_GROUNDWAT_URBAN=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_URBTBL,URBAN_ZONES);
WATERDEMAND_URBAN_SECT=WATERDEMAND_SURFWAT_URBAN+WATERDEMAND_GROUNDWAT_URBAN;
report D_URBAN=cover(if(boolean(URBAN_ZONES),WATERDEMAND_URBAN_SECT),scalar(0));

WATERDEMAND_SURFWAT_INDUSTR=lookupscalar(WATERDEMAND_SURFWAT_SECT_INDTBL,INDUSTR_ZONES);
WATERDEMAND_GROUNDWAT_INDUSTR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_INDTBL,INDUSTR_ZONES);
WATERDEMAND_INDUSTR_SECT=WATERDEMAND_SURFWAT_INDUSTR+WATERDEMAND_GROUNDWAT_INDUSTR;
report D_INDUSTR=cover(if(boolean(INDUSTR_ZONES),WATERDEMAND_INDUSTR_SECT),scalar(0));

WATERDEMAND_SURFWAT_AGR=lookupscalar(WATERDEMAND_SURFWAT_SECT_AGRTBL,AGR_ZONES);
WATERDEMAND_GROUNDWAT_AGR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_AGRTBL,AGR_ZONES);
WATERDEMAND_AGR_SECT=WATERDEMAND_SURFWAT_AGR+WATERDEMAND_GROUNDWAT_AGR;
report D_AGR=cover(if(boolean(AGR_ZONES),WATERDEMAND_AGR_SECT),scalar(0));

# water demand for irrigation specified per month
report D_AGR_001=cover(lookupscalar(AGR_PROP001TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_002=cover(lookupscalar(AGR_PROP002TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_003=cover(lookupscalar(AGR_PROP003TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_004=cover(lookupscalar(AGR_PROP004TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_005=cover(lookupscalar(AGR_PROP005TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_006=cover(lookupscalar(AGR_PROP006TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_007=cover(lookupscalar(AGR_PROP007TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_008=cover(lookupscalar(AGR_PROP008TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_009=cover(lookupscalar(AGR_PROP009TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_010=cover(lookupscalar(AGR_PROP010TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_011=cover(lookupscalar(AGR_PROP011TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_012=cover(lookupscalar(AGR_PROP012TBL,AGR_ZONES)*D_AGR,scalar(0));

#WATERDEMAND_SURFWAT_MINING=lookupscalar(WATERDEMAND_SURFWAT_SECT_MININGTBL,SECTORS);
#WATERDEMAND_GROUNDWAT_MINING=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_MININGTBL,SECTORS);
#WATERDEMAND_MINING_SECT=WATERDEMAND_SURFWAT_MINING+WATERDEMAND_GROUNDWAT_MINING;
#report D_MINING=cover(if(boolean(MINING_ZONES),WATERDEMAND_MINING_SECT),scalar(0));

# total gross water demand maps, absolute, per year and per month

report D_TOT=D_URBAN+D_INDUSTR+D_AGR;         #total gross water demand per year and per sector (m3.s-1); no mines in Suquia
#report D_TOT=D_URBAN+D_INDUSTR+D_AGR+D_MINING;        #total gross water demand per year and per sector (m3.s-1)

report D_TOT_001=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_001;
report D_TOT_002=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_002;
report D_TOT_003=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_003;
report D_TOT_004=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_004;
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```
report D_TOT_005=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_005;
report D_TOT_006=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_006;
report D_TOT_007=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_007;
report D_TOT_008=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_008;
report D_TOT_009=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_009;
report D_TOT_010=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_010;
report D_TOT_011=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_011;
report D_TOT_012=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_012;

# local water withdrawal-to-availability ratio per month (-)
# based on gross water water withdrawal; not accounting for return flows

report D_WA_001=D_TOT_001/max(qavg_jan,1E-10);
report D_WA_002=D_TOT_002/max(qavg_feb,1E-10);
report D_WA_003=D_TOT_003/max(qavg_mar,1E-10);
report D_WA_004=D_TOT_004/max(qavg_apr,1E-10);
report D_WA_005=D_TOT_005/max(qavg_may,1E-10);
report D_WA_006=D_TOT_006/max(qavg_jun,1E-10);
report D_WA_007=D_TOT_007/max(qavg_jul,1E-10);
report D_WA_008=D_TOT_008/max(qavg_aug,1E-10);
report D_WA_009=D_TOT_009/max(qavg_sep,1E-10);
report D_WA_010=D_TOT_010/max(qavg_oct,1E-10);
report D_WA_011=D_TOT_011/max(qavg_nov,1E-10);
report D_WA_012=D_TOT_012/max(qavg_dec,1E-10);

# Maps of friction encountered on supply from water supply points to water user units

# FRICDIST: Friction imposed by distance (m)
# Cut-off at 1E-10 to prevent a 0 argument to the log-function for WSI calculation
CELLLENGTH=sqrt(CELLAREA);
report FRICDIST=max(1E-10,spread(EXTRPOINTS,0,1*CELLLENGTH));

#friction imposed by differences in water quality between water supply point and water user units
report FRICWQUAL=spread(EXTRPOINTS,scalar(WATERQUALITYSTD),scalar(WATERQUALITYSTD));

# Water stress index per month based on friction-distance due to distance from water supply points, local water withdrawal-to-availability ratio,
# and the absolute value of the water demand
# Log-transformation on WSI to obtain comprehensible values
report WSI_001=log10(FRICDIST*D_WA_001+1);
report WSI_002=log10(FRICDIST*D_WA_002+1);
report WSI_003=log10(FRICDIST*D_WA_003+1);
report WSI_004=log10(FRICDIST*D_WA_004+1);
report WSI_005=log10(FRICDIST*D_WA_005+1);
report WSI_006=log10(FRICDIST*D_WA_006+1);
report WSI_007=log10(FRICDIST*D_WA_007+1);
report WSI_008=log10(FRICDIST*D_WA_008+1);
report WSI_009=log10(FRICDIST*D_WA_009+1);
report WSI_010=log10(FRICDIST*D_WA_010+1);
report WSI_011=log10(FRICDIST*D_WA_011+1);
report WSI_012=log10(FRICDIST*D_WA_012+1);

# Water stress index per month based on friction-distance due to differences in water quality, local water withdrawal-to-availability ratio,
# and the absolute value of the water demand
# Log-transformation on WSI to obtain comprehensible values
report WSI_WQ_001=log10(FRICWQUAL*D_WA_001+1);
report WSI_WQ_002=log10(FRICWQUAL*D_WA_002+1);
report WSI_WQ_003=log10(FRICWQUAL*D_WA_003+1);
report WSI_WQ_004=log10(FRICWQUAL*D_WA_004+1);
report WSI_WQ_005=log10(FRICWQUAL*D_WA_005+1);
report WSI_WQ_006=log10(FRICWQUAL*D_WA_006+1);
report WSI_WQ_007=log10(FRICWQUAL*D_WA_007+1);
report WSI_WQ_008=log10(FRICWQUAL*D_WA_008+1);
report WSI_WQ_009=log10(FRICWQUAL*D_WA_009+1);
report WSI_WQ_010=log10(FRICWQUAL*D_WA_010+1);
report WSI_WQ_011=log10(FRICWQUAL*D_WA_011+1);
report WSI_WQ_012=log10(FRICWQUAL*D_WA_012+1);
```

1.9.3 Cartographic Modelling Scripts for water demand and water stress Chile

```
# Cartographic modelling script file to calculate maps of water water withdrawal and water stress
# COROADO Project, Simone Verzandvoort, last revised 23 March 2014

#!--unitcell

binding

# General

# Mask of study area
AREA=maps\wsi\catclone.map;

# Digital elevation map
#DEM=maps\wsi\Chile_dem.map;

# slope gradient map
```

```
#GRAD=maps\wsi\grad.map;

# cell area (m2)
CELLAREA=maps\cellarea30.map;

# Settings for friction factors for water supply

# mean annual storage in stores 1, 2 and 3 over the period 2000-2010 (m)
# output from the PCRGLOBWB model
STOT_AVG=maps\wsi\stotavg_2000_2010.map;

# Water availability

# input: monthly averaged discharge maps for the period 2000-2010
# output from the PCRGLOBWB model
qavg_jan=maps\wsi\mean01.map;
qavg_feb=maps\wsi\mean02.map;
qavg_mar=maps\wsi\mean03.map;
qavg_apr=maps\wsi\mean04.map;
qavg_may=maps\wsi\mean05.map;
qavg_jun=maps\wsi\mean06.map;
qavg_jul=maps\wsi\mean07.map;
qavg_aug=maps\wsi\mean08.map;
qavg_sep=maps\wsi\mean09.map;
qavg_oct=maps\wsi\mean10.map;
qavg_nov=maps\wsi\mean11.map;
qavg_dec=maps\wsi\mean12.map;

# input: monthly averaged required environmental flow; not defined for Chile
#QENV_JAN=maps\wsi\q_env001.map;
#QENV_FEB=maps\wsi\q_env002.map;
#QENV_MAR=maps\wsi\q_env003.map;
#QENV_APR=maps\wsi\q_env004.map;
#QENV_MAY=maps\wsi\q_env005.map;
#QENV_JUN=maps\wsi\q_env006.map;
#QENV_JUL=maps\wsi\q_env007.map;
#QENV_AUG=maps\wsi\q_env008.map;
#QENV_SEP=maps\wsi\q_env009.map;
#QENV_OCT=maps\wsi\q_env010.map;
#QENV_NOV=maps\wsi\q_env011.map;
#QENV_DEC=maps\wsi\q_env012.map;

# Water demand (approximated by withdrawal)

# input: administrative and user zones
SECTORS=maps\wsi\sectors.map;      #map of administrative units to express water demand

# map with potential extractionpoints for all water uses
EXTRPOINTS=maps\wsi\all_extractionpointsID_nonmv.map;
URBAN_ZONES=maps\wsi\urban_zonesID.map;            #maps with urban, industrial, irrigated and mining zones
INDUSTR_ZONES=maps\wsi\industr_zonesID.map;
AGR_ZONES=maps\wsi\irrigation_zonesID.map;
MINING_ZONES=maps\wsi\actualmining_zonesID.map;

# input: gross annual average water demand data in tables per administrative sector, water type and user type (m3.s-1)
WATERDEMAND_SURFWAT_SECT_URBTBL=maps\wsi\waterdemand_surfwat_sectors_urban.tbl;     #table with water withdrawal from surface water for urban use
WATERDEMAND_GROUNDWAT_SECT_URBTBL=maps\wsi\waterdemand_groundwat_sectors_urban.tbl;     #table with water withdrawal from groundwater for urban use
WATERDEMAND_SURFWAT_SECT_INDTBL=maps\wsi\waterdemand_surfwat_sectors_industr.tbl;     #table with water withdrawal from surface water for industrial use
WATERDEMAND_GROUNDWAT_SECT_INDTBL=maps\wsi\waterdemand_groundwat_sectors_industr.tbl;     #table with water withdrawal from groundwater for industrial use
WATERDEMAND_SURFWAT_SECT_AGRTBL=maps\wsi\waterdemand_surfwat_sectors_agr.tbl;     #table with water withdrawal from surface water for agricultural use
WATERDEMAND_GROUNDWAT_SECT_AGRTBL=maps\wsi\waterdemand_groundwat_sectors_agr.tbl;     #table with water withdrawal from groundwater for agricultural use
WATERDEMAND_SURFWAT_SECT_MININGTBL=maps\wsi\waterdemand_surfwat_sectors_mining.tbl;     #table with water withdrawal from surface water for mining
WATERDEMAND_GROUNDWAT_SECT_MININGTBL=maps\wsi\waterdemand_groundwat_sectors_mining.tbl;     #table with water withdrawal from groundwater for mining

# input: monthly proportion of irrigation water demand
# source: information on water demand by aquifer sector provided by PUC in Sep 2013:
# "Tabla 4-18. Demanda hidrica bruta para los distintos sectores acuiferos (L/s)"
AGR_PROP001TBL=maps\wsi\agr_prop001.tbl;
AGR_PROP002TBL=maps\wsi\agr_prop002.tbl;
AGR_PROP003TBL=maps\wsi\agr_prop003.tbl;
AGR_PROP004TBL=maps\wsi\agr_prop004.tbl;
AGR_PROP005TBL=maps\wsi\agr_prop005.tbl;
AGR_PROP006TBL=maps\wsi\agr_prop006.tbl;
AGR_PROP007TBL=maps\wsi\agr_prop007.tbl;
AGR_PROP008TBL=maps\wsi\agr_prop008.tbl;
AGR_PROP009TBL=maps\wsi\agr_prop009.tbl;
AGR_PROP010TBL=maps\wsi\agr_prop010.tbl;
AGR_PROP011TBL=maps\wsi\agr_prop011.tbl;
AGR_PROP012TBL=maps\wsi\agr_prop012.tbl;
```

Output

# Gross water demand maps (absolute: in m3.s-1 per year)
D_URBAN=results\wsi\D_urban.map;
D_INDUSTR=results\wsi\D_industr.map;
D_AGR=results\wsi\D_agr.map;
D_MINING=results\wsi\D_mining.map;

# Monthly water demand maps for irrigation (m3.s-1 per month)
D_AGR_001=results\wsi\D_agr0001.map;
D_AGR_002=results\wsi\D_agr0002.map;
D_AGR_003=results\wsi\D_agr0003.map;
D_AGR_004=results\wsi\D_agr0004.map;
D_AGR_005=results\wsi\D_agr0005.map;
D_AGR_006=results\wsi\D_agr0006.map;
D_AGR_007=results\wsi\D_agr0007.map;
D_AGR_008=results\wsi\D_agr0008.map;
D_AGR_009=results\wsi\D_agr0009.map;
D_AGR_010=results\wsi\D_agr0010.map;
D_AGR_011=results\wsi\D_agr0011.map;
D_AGR_012=results\wsi\D_agr0012.map;

annual and monthly total water demand maps (from all sectors) (m3.s-1)

D_TOT=results\wsi\D_tot.map;

D_TOT_001=results\wsi\D_tot001.map;
D_TOT_002=results\wsi\D_tot002.map;
D_TOT_003=results\wsi\D_tot003.map;
D_TOT_004=results\wsi\D_tot004.map;
D_TOT_005=results\wsi\D_tot005.map;
D_TOT_006=results\wsi\D_tot006.map;
D_TOT_007=results\wsi\D_tot007.map;
D_TOT_008=results\wsi\D_tot008.map;
D_TOT_009=results\wsi\D_tot009.map;
D_TOT_010=results\wsi\D_tot010.map;
D_TOT_011=results\wsi\D_tot011.map;
D_TOT_012=results\wsi\D_tot012.map;

# maps of ocal water withdrawal-to-availability ratio per month (-)
D_WA_001=results\wsi\D_wa001.map;
D_WA_002=results\wsi\D_wa002.map;
D_WA_003=results\wsi\D_wa003.map;
D_WA_004=results\wsi\D_wa004.map;
D_WA_005=results\wsi\D_wa005.map;
D_WA_006=results\wsi\D_wa006.map;
D_WA_007=results\wsi\D_wa007.map;
D_WA_008=results\wsi\D_wa008.map;
D_WA_009=results\wsi\D_wa009.map;
D_WA_010=results\wsi\D_wa010.map;
D_WA_011=results\wsi\D_wa011.map;
D_WA_012=results\wsi\D_wa012.map;

# map of friction by distance
FRICDIST=results\wsi\fricdist.map;

# map of friction by unavailable water storage
FRICSTOT=results\wsi\fricstot.map;

# Water stress index maps based on friction by distance to water supply points (default)
WSI_001=results\wsi\wsi_001.map;
WSI_002=results\wsi\wsi_002.map;
WSI_003=results\wsi\wsi_003.map;
WSI_004=results\wsi\wsi_004.map;
WSI_005=results\wsi\wsi_005.map;
WSI_006=results\wsi\wsi_006.map;
WSI_007=results\wsi\wsi_007.map;
WSI_008=results\wsi\wsi_008.map;
WSI_009=results\wsi\wsi_009.map;
WSI_010=results\wsi\wsi_010.map;
WSI_011=results\wsi\wsi_011.map;
WSI_012=results\wsi\wsi_012.map;

# water stress index maps by available water storage
WSI_STOT_001=results\wsi\wsi_stot_001.map;
WSI_STOT_002=results\wsi\wsi_stot_002.map;
WSI_STOT_003=results\wsi\wsi_stot_003.map;
WSI_STOT_004=results\wsi\wsi_stot_004.map;
WSI_STOT_005=results\wsi\wsi_stot_005.map;
WSI_STOT_006=results\wsi\wsi_stot_006.map;
WSI_STOT_007=results\wsi\wsi_stot_007.map;
WSI_STOT_008=results\wsi\wsi_stot_008.map;
WSI_STOT_009=results\wsi\wsi_stot_009.map;
WSI_STOT_010=results\wsi\wsi_stot_010.map;
WSI_STOT_011=results\wsi\wsi_stot_011.map;
WSI_STOT_012=results\wsi\wsi_stot_012.map;

```
initial
# calculation of water demand maps per administrative sector and/or in water user zones (m3.s-1 per year and per administrative sector or user zone)
# water demand from surface water and groundwater is calculated separately
# water demand satisfied from sources outside the catchment (e.g. desalinated or imported water) should be subtracted from water demand

# urban/domestic water use
WATERDEMAND_SURFWAT_URBAN=lookupscalar(WATERDEMAND_SURFWAT_SECT_URBTBL,SECTORS);
WATERDEMAND_GROUNDWAT_URBAN=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_URBTBL,SECTORS);
WATERDEMAND_URBAN_SECT=WATERDEMAND_SURFWAT_URBAN+WATERDEMAND_GROUNDWAT_URBAN;
report D_URBAN=cover(if(boolean(URBAN_ZONES),WATERDEMAND_URBAN_SECT),scalar(0));

# industrial water use
WATERDEMAND_SURFWAT_INDUSTR=lookupscalar(WATERDEMAND_SURFWAT_SECT_INDTBL,SECTORS);
WATERDEMAND_GROUNDWAT_INDUSTR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_INDTBL,SECTORS);
WATERDEMAND_INDUSTR_SECT=WATERDEMAND_SURFWAT_INDUSTR+WATERDEMAND_GROUNDWAT_INDUSTR;
report D_INDUSTR=cover(if(boolean(INDUSTR_ZONES),WATERDEMAND_INDUSTR_SECT),scalar(0));

# water use for irrigation
WATERDEMAND_SURFWAT_AGR=lookupscalar(WATERDEMAND_SURFWAT_SECT_AGRTBL,SECTORS);
WATERDEMAND_GROUNDWAT_AGR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_AGRTBL,SECTORS);
WATERDEMAND_AGR_SECT=WATERDEMAND_SURFWAT_AGR+WATERDEMAND_GROUNDWAT_AGR;
report D_AGR=cover(if(boolean(AGR_ZONES),WATERDEMAND_AGR_SECT),scalar(0));

# water demand for irrigation specified per month
report D_AGR_001=cover(lookupscalar(AGR_PROP001TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_002=cover(lookupscalar(AGR_PROP002TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_003=cover(lookupscalar(AGR_PROP003TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_004=cover(lookupscalar(AGR_PROP004TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_005=cover(lookupscalar(AGR_PROP005TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_006=cover(lookupscalar(AGR_PROP006TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_007=cover(lookupscalar(AGR_PROP007TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_008=cover(lookupscalar(AGR_PROP008TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_009=cover(lookupscalar(AGR_PROP009TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_010=cover(lookupscalar(AGR_PROP010TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_011=cover(lookupscalar(AGR_PROP011TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_012=cover(lookupscalar(AGR_PROP012TBL,AGR_ZONES)*D_AGR,scalar(0));

# water use for mining
WATERDEMAND_SURFWAT_MINING=lookupscalar(WATERDEMAND_SURFWAT_SECT_MININGTBL,SECTORS);
WATERDEMAND_GROUNDWAT_MINING=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_MININGTBL,SECTORS);
WATERDEMAND_MINING_SECT=WATERDEMAND_SURFWAT_MINING+WATERDEMAND_GROUNDWAT_MINING;
report D_MINING=cover(if(boolean(MINING_ZONES),WATERDEMAND_MINING_SECT),scalar(0));

# total gross water demand maps, absolute, per year and per month

report D_TOT=D_URBAN+D_INDUSTR+D_AGR+D_MINING;        #total gross water demand per year and per sector (m3.s-1)

report D_TOT_001=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_001+(D_MINING/12);
report D_TOT_002=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_002+(D_MINING/12);
report D_TOT_003=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_003+(D_MINING/12);
report D_TOT_004=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_004+(D_MINING/12);
report D_TOT_005=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_005+(D_MINING/12);
report D_TOT_006=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_006+(D_MINING/12);
report D_TOT_007=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_007+(D_MINING/12);
report D_TOT_008=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_008+(D_MINING/12);
report D_TOT_009=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_009+(D_MINING/12);
report D_TOT_010=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_010+(D_MINING/12);
report D_TOT_011=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_011+(D_MINING/12);
report D_TOT_012=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_012+(D_MINING/12);

# local water withdrawal-to-availability ratio per month (-)
# based on gross water water withdrawal; not accounting for return flows

report D_WA_001=D_TOT_001/max(qavg_jan,1E-10);
report D_WA_002=D_TOT_002/max(qavg_feb,1E-10);
report D_WA_003=D_TOT_003/max(qavg_mar,1E-10);
report D_WA_004=D_TOT_004/max(qavg_apr,1E-10);
report D_WA_005=D_TOT_005/max(qavg_may,1E-10);
report D_WA_006=D_TOT_006/max(qavg_jun,1E-10);
report D_WA_007=D_TOT_007/max(qavg_jul,1E-10);
report D_WA_008=D_TOT_008/max(qavg_aug,1E-10);
report D_WA_009=D_TOT_009/max(qavg_sep,1E-10);
report D_WA_010=D_TOT_010/max(qavg_oct,1E-10);
report D_WA_011=D_TOT_011/max(qavg_nov,1E-10);
report D_WA_012=D_TOT_012/max(qavg_dec,1E-10);

# maps of friction encountered on supply from water supply points to water user units

# DISTANCE FROM WATER SUPPLY POINTS IS NOT A GOOD CRITERION FOR WATER STRESS in Chile, since water user units are all close to water
supply points
# Water stress is caused by the use of more surface and groundwater than available on the long term
# Therefore the available storage in layers 1, 2 and 3 is used as the fricttion factor to the water supply
# This factor is the model output STOT_AVG, or the mean available total storage in stores 1, 2 and 3 in m.day-1

# FRICDIST: Friction imposed by distance (m)
# Cut-off at 1E-10 to prevent a 0 argument to the log-function for WSI calculation
```

```
CELLLENGTH=sqrt(CELLAREA);
report FRICDIST=max(1E-10,spread(EXTRPOINTS,0,1*CELLLENGTH));

# FRICSTOT: friction imposed by unavailable water storage
report FRICSTOT=spread(EXTRPOINTS,0,1/STOT_AVG);

# Water stress index per month based on friction-distance due to distance from water supply points, local water withdrawal-to-availability ratio,
# and the absolute value of the water demand
# Log-transformation on WSI to obtain comprehensible values
report WSI_001=log10(FRICDIST*D_WA_001+1);
report WSI_002=log10(FRICDIST*D_WA_002+1);
report WSI_003=log10(FRICDIST*D_WA_003+1);
report WSI_004=log10(FRICDIST*D_WA_004+1);
report WSI_005=log10(FRICDIST*D_WA_005+1);
report WSI_006=log10(FRICDIST*D_WA_006+1);
report WSI_007=log10(FRICDIST*D_WA_007+1);
report WSI_008=log10(FRICDIST*D_WA_008+1);
report WSI_009=log10(FRICDIST*D_WA_009+1);
report WSI_010=log10(FRICDIST*D_WA_010+1);
report WSI_011=log10(FRICDIST*D_WA_011+1);
report WSI_012=log10(FRICDIST*D_WA_012+1);

# Water stress index per month based on friction-distance due to unavailable water storage, local water withdrawal-to-availability ratio,
# and the absolute value of the water demand
# Log-transformation on WSI to obtain comprehensible values
report WSI_STOT_001=log10(FRICSTOT*D_WA_001+1);
report WSI_STOT_002=log10(FRICSTOT*D_WA_002+1);
report WSI_STOT_003=log10(FRICSTOT*D_WA_003+1);
report WSI_STOT_004=log10(FRICSTOT*D_WA_004+1);
report WSI_STOT_005=log10(FRICSTOT*D_WA_005+1);
report WSI_STOT_006=log10(FRICSTOT*D_WA_006+1);
report WSI_STOT_007=log10(FRICSTOT*D_WA_007+1);
report WSI_STOT_008=log10(FRICSTOT*D_WA_008+1);
report WSI_STOT_009=log10(FRICSTOT*D_WA_009+1);
report WSI_STOT_010=log10(FRICSTOT*D_WA_010+1);
report WSI_STOT_011=log10(FRICSTOT*D_WA_011+1);
report WSI_STOT_012=log10(FRICSTOT*D_WA_012+1);
```

1.9.4 Cartographic Modelling Scripts for water demand and water stress Mexico

```
# Cartographic modelling script file to calculate maps of water water withdrawal and water stress
# COROADO Project, Simone Verzandvoort, last revised October 2014

#!--unitcell

binding

# General

# Mask of study area
AREA=maps\catclone.map;

# Digital elevation map
DEM=maps\Mdem.map;

# slope gradient map
GRAD=maps\grad.map;

# cell area (m2)
CELLAREA=maps\cellarea30.map;

# Settings for friction factors for water supply
# no specific settings for Mexico; distance as friction factor is default

# Water availability

# input: monthly averaged discharge maps for the period 2000-2010
qavg_jan=maps\wsi\mean01.map;
qavg_feb=maps\wsi\mean02.map;
qavg_mar=maps\wsi\mean03.map;
qavg_apr=maps\wsi\mean04.map;
qavg_may=maps\wsi\mean05.map;
qavg_jun=maps\wsi\mean06.map;
qavg_jul=maps\wsi\mean07.map;
qavg_aug=maps\wsi\mean08.map;
qavg_sep=maps\wsi\mean09.map;
qavg_oct=maps\wsi\mean10.map;
qavg_nov=maps\wsi\mean11.map;
qavg_dec=maps\wsi\mean12.map;

# input: monthly averaged required environmental flow
# no environmental flow requirement defined for Mexico
#QENV_JAN=maps\wsi\q_env001.map;
#QENV_FEB=maps\wsi\q_env002.map;
#QENV_MAR=maps\wsi\q_env003.map;
```

#QENV_APR=maps\wsi\q_env004.map;
#QENV_MAY=maps\wsi\q_env005.map;
#QENV_JUN=maps\wsi\q_env006.map;
#QENV_JUL=maps\wsi\q_env007.map;
#QENV_AUG=maps\wsi\q_env008.map;
#QENV_SEP=maps\wsi\q_env009.map;
#QENV_OCT=maps\wsi\q_env010.map;
#QENV_NOV=maps\wsi\q_env011.map;
#QENV_DEC=maps\wsi\q_env012.map;

Water demand (approximated by withdrawal)
input: administrative and user zones

#SECTORS=maps\wsi\sectors.map; map of administrative units to express water demand; not applicable to Rop Bravo Lower River basin
#map with potential extractionpoints for all water uses: includes streams, canals, supply points
EXTRPOINTS=maps\wsi\all_extractionpointsID_nonmv.map;
URBAN_ZONES=maps\wsi\urban_zonesID.map; #maps with urban, industrial, irrigated and mining zones
INDUSTR_ZONES=maps\wsi\industr_zonesID.map;
AGR_ZONES=maps\wsi\irrigation_zonesID.map;
#MINING_ZONES=maps\wsi\actualmining_zonesID.map; # no mines in Rio Bravo Lower River Basin

# input: gross annual average water demand data in tables per sector, water type and user type (m3.s-1)
WATERDEMAND_SURFWAT_SECT_URBTBL=maps\wsi\waterdemand_surfwat_sectors_urban.tbl; #table with water withdrawal from surface water for urban use
WATERDEMAND_GROUNDWAT_SECT_URBTBL=maps\wsi\waterdemand_groundwat_sectors_urban.tbl; #table with water withdrawal from groundwater for urban use
WATERDEMAND_SURFWAT_SECT_INDTBL=maps\wsi\waterdemand_surfwat_sectors_industr.tbl; #table with water withdrawal from surface water for industrial use
WATERDEMAND_GROUNDWAT_SECT_INDTBL=maps\wsi\waterdemand_groundwat_sectors_industr.tbl; #table with water withdrawal from groundwater for industrial use
WATERDEMAND_SURFWAT_SECT_AGRTBL=maps\wsi\waterdemand_surfwat_sectors_agr.tbl; #table with water withdrawal from surface water for agricultural use
WATERDEMAND_GROUNDWAT_SECT_AGRTBL=maps\wsi\waterdemand_groundwat_sectors_agr.tbl; #table with water withdrawal from groundwater for agricultural use
#WATERDEMAND_SURFWAT_SECT_MININGTBL=maps\wsi\waterdemand_surfwat_sectors_mining.tbl; #table with water withdrawal from surface water for mining
#WATERDEMAND_GROUNDWAT_SECT_MININGTBL=maps\wsi\waterdemand_groundwat_sectors_mining.tbl; #table with water withdrawal from groundwater for mining

# input: monthly proportion of irrigation water demand
AGR_PROP001TBL=maps\wsi\agr_prop001.tbl;
AGR_PROP002TBL=maps\wsi\agr_prop002.tbl;
AGR_PROP003TBL=maps\wsi\agr_prop003.tbl;
AGR_PROP004TBL=maps\wsi\agr_prop004.tbl;
AGR_PROP005TBL=maps\wsi\agr_prop005.tbl;
AGR_PROP006TBL=maps\wsi\agr_prop006.tbl;
AGR_PROP007TBL=maps\wsi\agr_prop007.tbl;
AGR_PROP008TBL=maps\wsi\agr_prop008.tbl;
AGR_PROP009TBL=maps\wsi\agr_prop009.tbl;
AGR_PROP010TBL=maps\wsi\agr_prop010.tbl;
AGR_PROP011TBL=maps\wsi\agr_prop011.tbl;
AGR_PROP012TBL=maps\wsi\agr_prop012.tbl;

Output

# Gross water demand maps (absolute: in m3.s-1 per year)
D_URBAN=results\wsi\D_urban.map;
D_INDUSTR=results\wsi\D_industr.map;
D_AGR=results\wsi\D_agr.map;

# Monthly water demand maps for irrigation (m3.s-1 per month)
D_AGR_001=results\wsi\D_agr0001.map;
D_AGR_002=results\wsi\D_agr0002.map;
D_AGR_003=results\wsi\D_agr0003.map;
D_AGR_004=results\wsi\D_agr0004.map;
D_AGR_005=results\wsi\D_agr0005.map;
D_AGR_006=results\wsi\D_agr0006.map;
D_AGR_007=results\wsi\D_agr0007.map;
D_AGR_008=results\wsi\D_agr0008.map;
D_AGR_009=results\wsi\D_agr0009.map;
D_AGR_010=results\wsi\D_agr0010.map;
D_AGR_011=results\wsi\D_agr0011.map;
D_AGR_012=results\wsi\D_agr0012.map;

#D_MINING=results\wsi\D_mining.map; # no mines in Rio Bravo Lower River Basin

annual and monthly total water demand maps (from all sectors)

D_TOT=results\wsi\D_tot.map;

D_TOT_001=results\wsi\D_tot001.map;
D_TOT_002=results\wsi\D_tot002.map;
D_TOT_003=results\wsi\D_tot003.map;
D_TOT_004=results\wsi\D_tot004.map;
D_TOT_005=results\wsi\D_tot005.map;
D_TOT_006=results\wsi\D_tot006.map;
D_TOT_007=results\wsi\D_tot007.map;

```
D_TOT_008=results\wsi\D_tot008.map;
D_TOT_009=results\wsi\D_tot009.map;
D_TOT_010=results\wsi\D_tot010.map;
D_TOT_011=results\wsi\D_tot011.map;
D_TOT_012=results\wsi\D_tot012.map;

# maps of local water withdrawal-to-availability ratio per month (-)
D_WA_001=results\wsi\D_wa001.map;
D_WA_002=results\wsi\D_wa002.map;
D_WA_003=results\wsi\D_wa003.map;
D_WA_004=results\wsi\D_wa004.map;
D_WA_005=results\wsi\D_wa005.map;
D_WA_006=results\wsi\D_wa006.map;
D_WA_007=results\wsi\D_wa007.map;
D_WA_008=results\wsi\D_wa008.map;
D_WA_009=results\wsi\D_wa009.map;
D_WA_010=results\wsi\D_wa010.map;
D_WA_011=results\wsi\D_wa011.map;
D_WA_012=results\wsi\D_wa012.map;

# Map of friction by distance
FRICDIST=results\wsi\fricdist.map;

# Water stress index maps based on friction by distance to water supply points (default)
WSI_001=results\wsi\wsi_001.map;
WSI_002=results\wsi\wsi_002.map;
WSI_003=results\wsi\wsi_003.map;
WSI_004=results\wsi\wsi_004.map;
WSI_005=results\wsi\wsi_005.map;
WSI_006=results\wsi\wsi_006.map;
WSI_007=results\wsi\wsi_007.map;
WSI_008=results\wsi\wsi_008.map;
WSI_009=results\wsi\wsi_009.map;
WSI_010=results\wsi\wsi_010.map;
WSI_011=results\wsi\wsi_011.map;
WSI_012=results\wsi\wsi_012.map;


initial
# calculation of water demand maps per administrative sector and/or in water user zones (m3.s-1 per year and per administrative sector or user zone)
# water demand from surface water and groundwater is calculated separately
# water demand satisfied from sources outside the catchment (e.g. desalinated or imported water) should be subtracted from water demand

WATERDEMAND_SURFWAT_URBAN=lookupscalar(WATERDEMAND_SURFWAT_SECT_URBTBL,URBAN_ZONES);
WATERDEMAND_GROUNDWAT_URBAN=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_URBTBL,URBAN_ZONES);
WATERDEMAND_URBAN_SECT=WATERDEMAND_SURFWAT_URBAN+WATERDEMAND_GROUNDWAT_URBAN;
report D_URBAN=cover(if(boolean(URBAN_ZONES),WATERDEMAND_URBAN_SECT),scalar(0));

WATERDEMAND_SURFWAT_INDUSTR=lookupscalar(WATERDEMAND_SURFWAT_SECT_INDTBL,INDUSTR_ZONES);
WATERDEMAND_GROUNDWAT_INDUSTR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_INDTBL,INDUSTR_ZONES);
WATERDEMAND_INDUSTR_SECT=WATERDEMAND_SURFWAT_INDUSTR+WATERDEMAND_GROUNDWAT_INDUSTR;
report D_INDUSTR=cover(if(boolean(INDUSTR_ZONES),WATERDEMAND_INDUSTR_SECT),scalar(0));

WATERDEMAND_SURFWAT_AGR=lookupscalar(WATERDEMAND_SURFWAT_SECT_AGRTBL,AGR_ZONES);
WATERDEMAND_GROUNDWAT_AGR=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_AGRTBL,AGR_ZONES);
WATERDEMAND_AGR_SECT=WATERDEMAND_SURFWAT_AGR+WATERDEMAND_GROUNDWAT_AGR;
report D_AGR=cover(if(boolean(AGR_ZONES),WATERDEMAND_AGR_SECT),scalar(0));

# water demand for irrigation specified per month
report D_AGR_001=cover(lookupscalar(AGR_PROP001TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_002=cover(lookupscalar(AGR_PROP002TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_003=cover(lookupscalar(AGR_PROP003TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_004=cover(lookupscalar(AGR_PROP004TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_005=cover(lookupscalar(AGR_PROP005TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_006=cover(lookupscalar(AGR_PROP006TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_007=cover(lookupscalar(AGR_PROP007TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_008=cover(lookupscalar(AGR_PROP008TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_009=cover(lookupscalar(AGR_PROP009TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_010=cover(lookupscalar(AGR_PROP010TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_011=cover(lookupscalar(AGR_PROP011TBL,AGR_ZONES)*D_AGR,scalar(0));
report D_AGR_012=cover(lookupscalar(AGR_PROP012TBL,AGR_ZONES)*D_AGR,scalar(0));

#WATERDEMAND_SURFWAT_MINING=lookupscalar(WATERDEMAND_SURFWAT_SECT_MININGTBL,SECTORS);
#WATERDEMAND_GROUNDWAT_MINING=lookupscalar(WATERDEMAND_GROUNDWAT_SECT_MININGTBL,SECTORS);
#WATERDEMAND_MINING_SECT=WATERDEMAND_SURFWAT_MINING+WATERDEMAND_GROUNDWAT_MINING;
#report D_MINING=cover(if(boolean(MINING_ZONES),WATERDEMAND_MINING_SECT),scalar(0));

# total gross water demand maps, absolute, per year and per month

report D_TOT=D_URBAN+D_INDUSTR+D_AGR;        #total gross water demand per year and per sector (m3.s-1); no mines in case study Mexico
#report D_TOT=D_URBAN+D_INDUSTR+D_AGR+D_MINING;        #total gross water demand per year and per sector (m3.s-1)

report D_TOT_001=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_001;
report D_TOT_002=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_002;
report D_TOT_003=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_003;
report D_TOT_004=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_004;
report D_TOT_005=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_005;
```

```
report D_TOT_006=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_006;
report D_TOT_007=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_007;
report D_TOT_008=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_008;
report D_TOT_009=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_009;
report D_TOT_010=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_010;
report D_TOT_011=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_011;
report D_TOT_012=(D_URBAN/12)+(D_INDUSTR/12)+D_AGR_012;

# local water withdrawal-to-availability ratio per month (-)
# based on gross water withdrawal; not accounting for return flows

report D_WA_001=D_TOT_001/max(qavg_jan,1E-10);
report D_WA_002=D_TOT_002/max(qavg_feb,1E-10);
report D_WA_003=D_TOT_003/max(qavg_mar,1E-10);
report D_WA_004=D_TOT_004/max(qavg_apr,1E-10);
report D_WA_005=D_TOT_005/max(qavg_may,1E-10);
report D_WA_006=D_TOT_006/max(qavg_jun,1E-10);
report D_WA_007=D_TOT_007/max(qavg_jul,1E-10);
report D_WA_008=D_TOT_008/max(qavg_aug,1E-10);
report D_WA_009=D_TOT_009/max(qavg_sep,1E-10);
report D_WA_010=D_TOT_010/max(qavg_oct,1E-10);
report D_WA_011=D_TOT_011/max(qavg_nov,1E-10);
report D_WA_012=D_TOT_012/max(qavg_dec,1E-10);

# Maps of friction encountered on supply from water supply points to water user units
# FRICDIST: Friction imposed by distance (m)
# Cut-off at 1E-10 to prevent a 0 argument to the log-function for WSI calculation

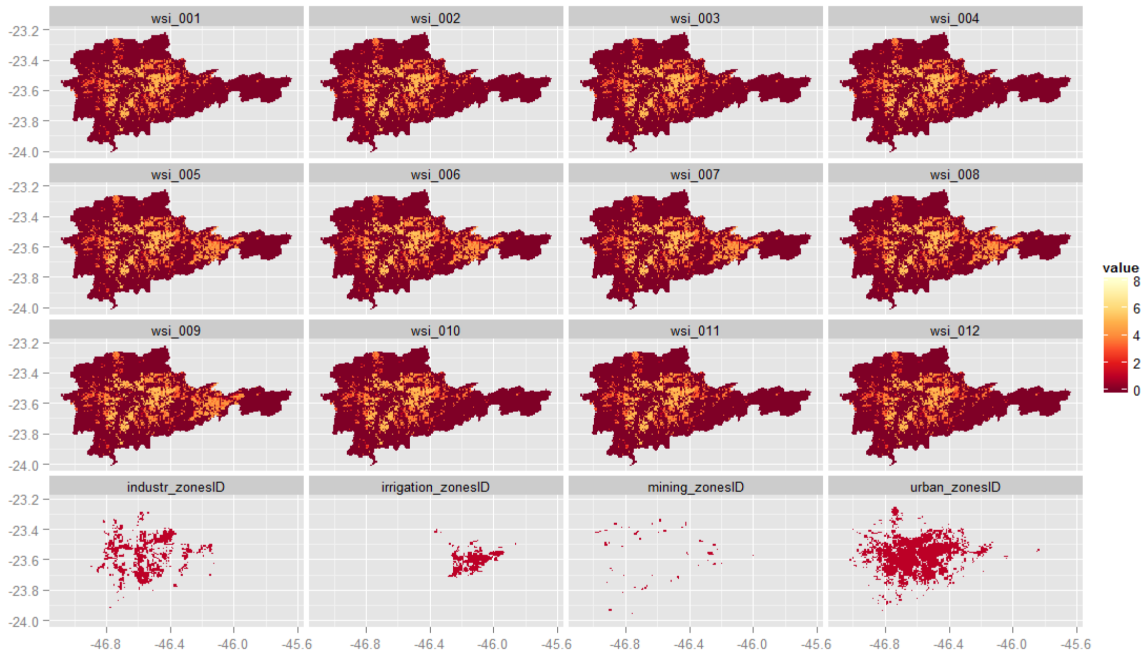
CELLLENGTH=sqrt(CELLAREA);
report FRICDIST=max(1E-10,spread(EXTRPOINTS,0,1*CELLLENGTH));

# Water stress index per month based on friction-distance, local water withdrawal-to-availability ratio,
# and the absolute value of the water demand
# Log-transformation on WSI to obtain comprehensible values
report WSI_001=log10(FRICDIST*D_WA_001+1);
report WSI_002=log10(FRICDIST*D_WA_002+1);
report WSI_003=log10(FRICDIST*D_WA_003+1);
report WSI_004=log10(FRICDIST*D_WA_004+1);
report WSI_005=log10(FRICDIST*D_WA_005+1);
report WSI_006=log10(FRICDIST*D_WA_006+1);
report WSI_007=log10(FRICDIST*D_WA_007+1);
report WSI_008=log10(FRICDIST*D_WA_008+1);
report WSI_009=log10(FRICDIST*D_WA_009+1);
report WSI_010=log10(FRICDIST*D_WA_010+1);
report WSI_011=log10(FRICDIST*D_WA_011+1);
report WSI_012=log10(FRICDIST*D_WA_012+1);
```

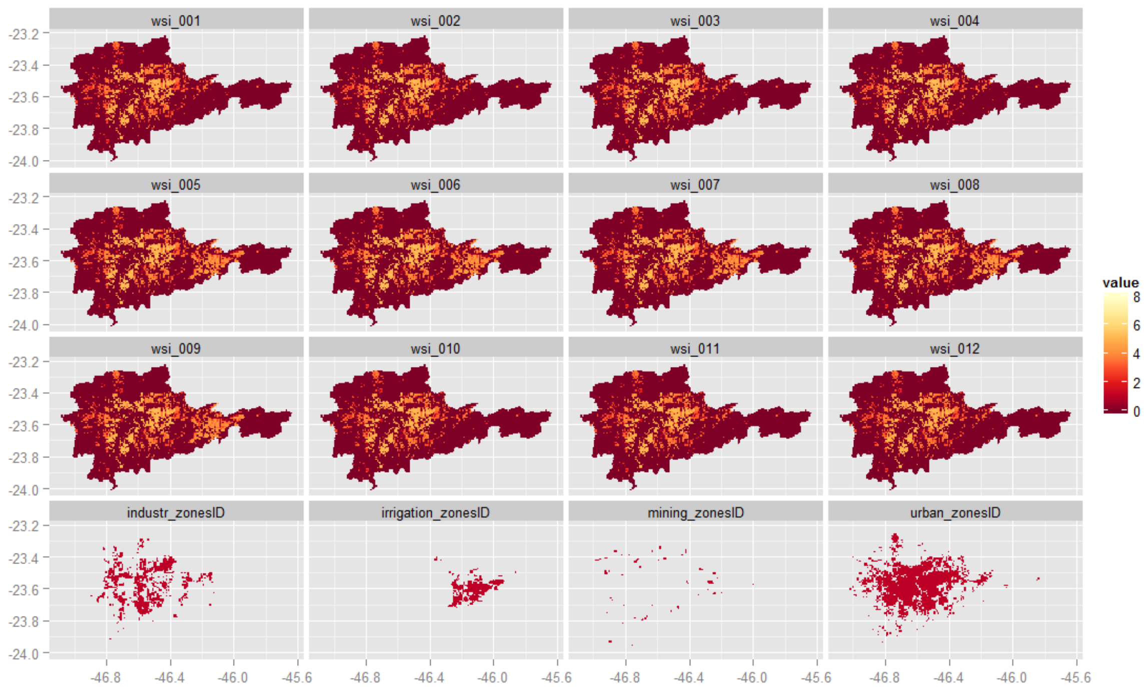
1.10 Results of the Water Stress Assessment for the case study areas in Brazil, Chile and Mexico

Results for the baseline period are shown for conditions of minimum, mean and maximum potential blue water availability. Results for the climate change scenarios P10T90 and P90T10 are shown for the mean potential blue water availability. Results for all conditions are available as HTML files through the COROADO DSS (to be arranged with WP3 or WP6).

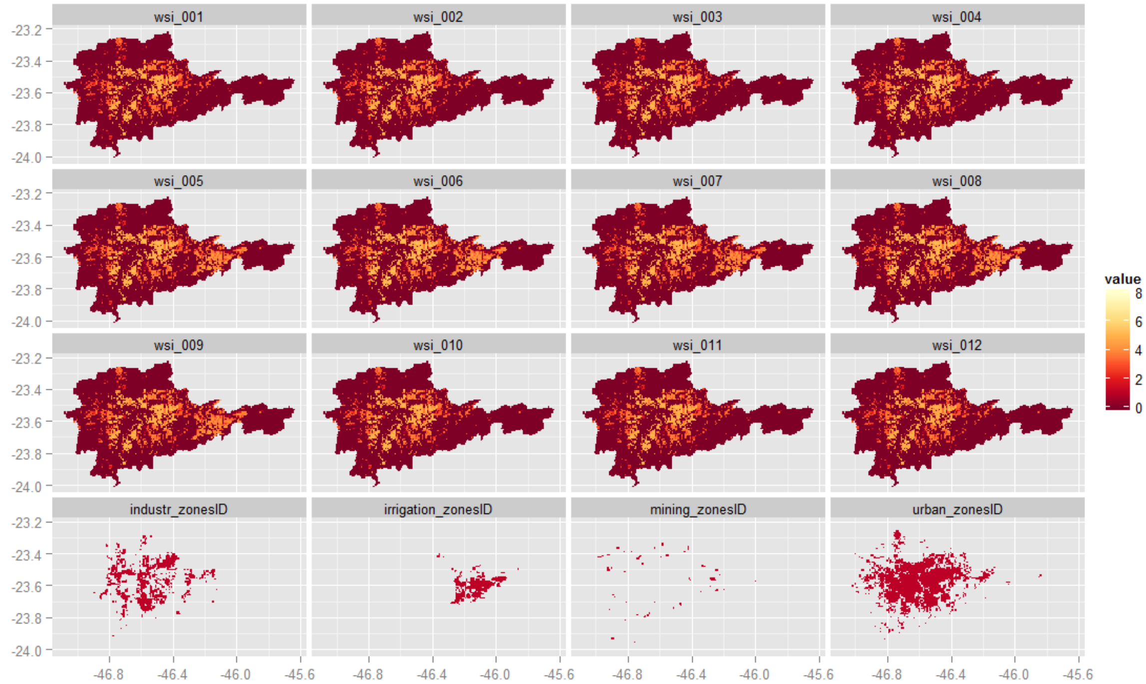
1.10.1 Water Stress Assessment Brazil



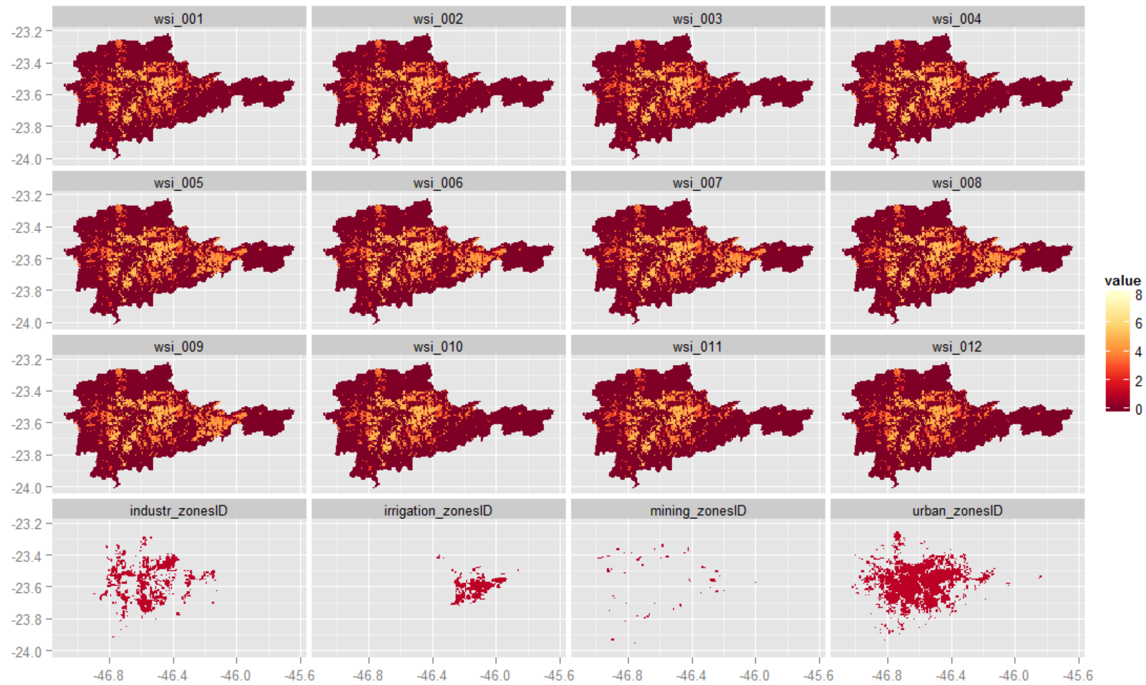
(a) WSI based on minimum potential blue water availability under baseline conditions



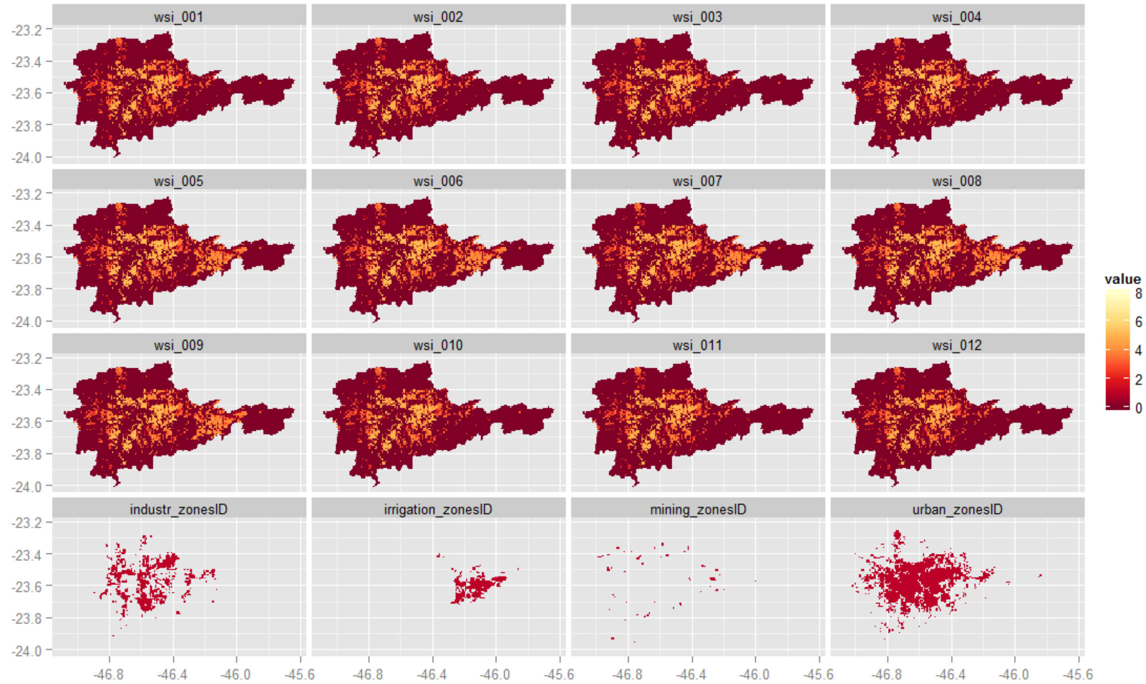
(b) WSI based on mean potential blue water availability under baseline conditions



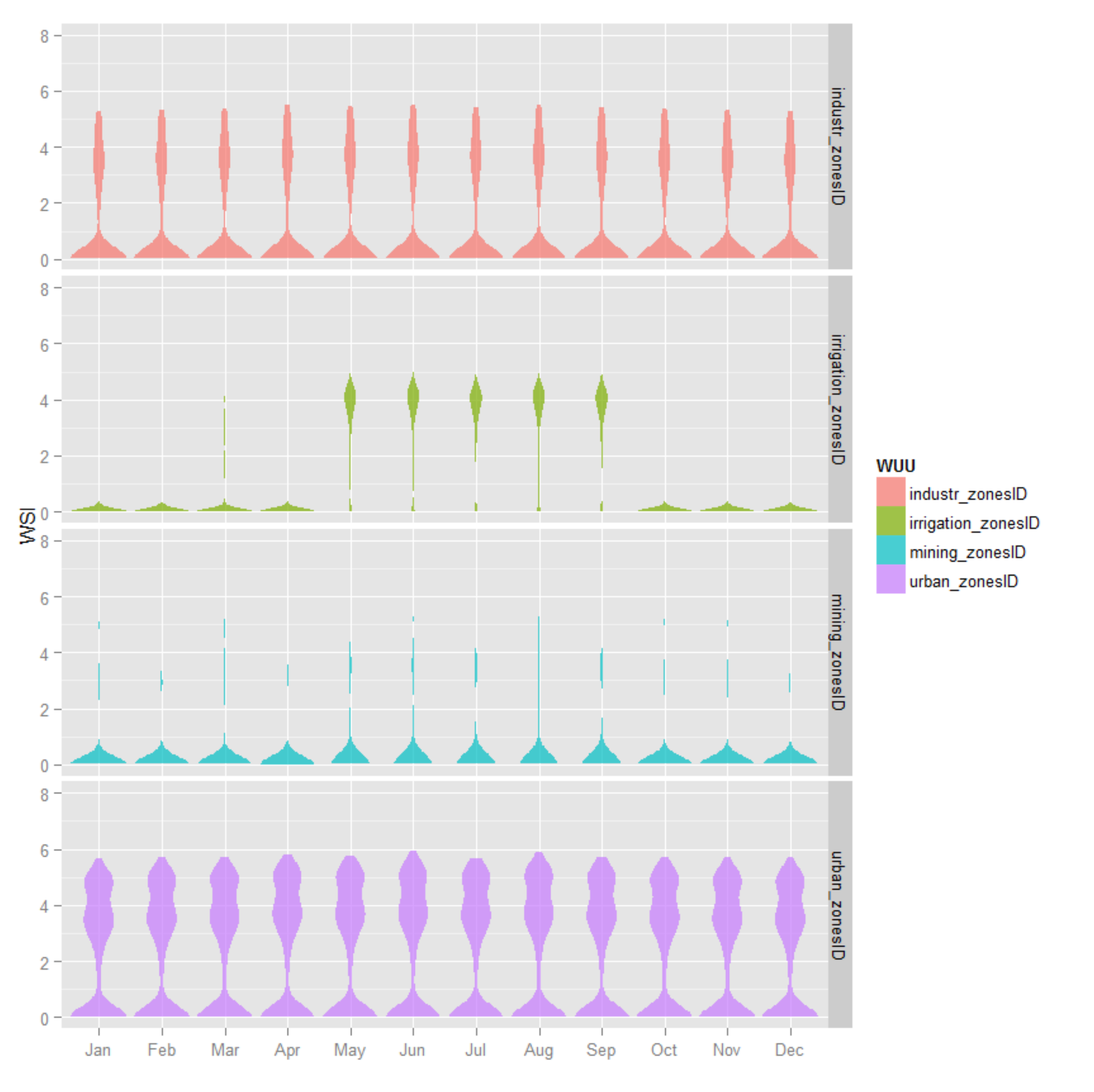
(c) WSI based on maximum potential blue water availability under baseline conditions



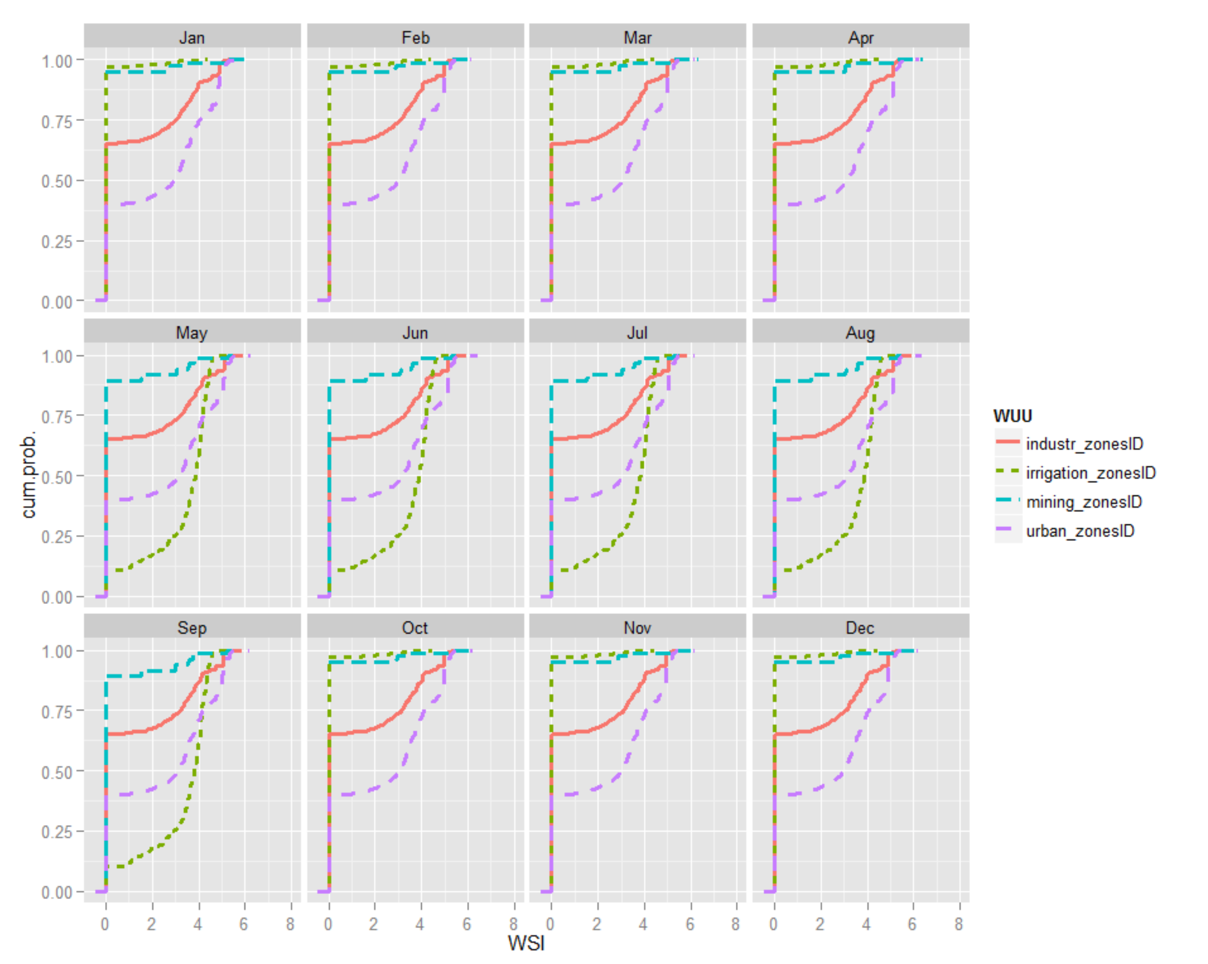
(d) WSI based on mean potential blue water availability under scenario P10T90



(e) WSI based on mean potential blue water availability under scenario P90T10



Violin plot for baseline situation, mean WA



Sectoral plot for baseline situation, mean WA

1.10.2 Chile

Same figures

1.10.3 Mexico

Same figures

1.11 Matching wastewater producers and re-users in the COROADO case study sites

Annex 1.11 consists of the reports of the application of the WP4-tool for wastewater production mapping and matching wastewater producers to reusers to the four COROADO case study sites. These reports are delivered in separate reports in pdf format to the coordinator.

1.12 List of products and tools of the WP4-tool

Step	Products	Temporal resolution/ domain	Spatial resolution	Tools	Data
1. Assess blue water availability	Water availability maps Water balance	Monthly-seasonal Baseline (2000-2010) Future (CC+D) (2030-2050	30 arcsecs River basin	PCRGLOBWB v1.0 Climate scenario framework	Global datasets (lithology, soils, land cover, DEM, FAO) CRU TS, ERA-40, ERA-Interim Study site datasets Worldclim
2. Assess blue water demand	Water demand maps	Quasi-monthly/ annual Baseline Future	30 arcsecs	PCRaster	Study site datasets & projections Projections from literature
3. Identify zones with water stress	Water stress index maps	Monthly Baseline Future	30 arcsecs	Water stress index map tool	From steps 1 and 2
4. Find wastewater producers	Wastewater production map	Annual Baseline (2000-2010)	Showing production units	ArcGIS	Study site datasets Google Earth
5. Find potential wastewater reusers	Water user map	Annual Baseline (2000-2010)	Showing water user units	ArcGIS Spatial algorithm (WP6)	Study site datasets Criteria
6. Select and evaluate WR&R options	Technology fact sheets	none	none	POSEIDON tool	Study site datasets Expert knowledge

1.13 List of available geo-information from WP4 for the COROADO WebGIS and DSS

Syntax:
<C> case study site
<cc> Climate change scenario
<d> day of the year (ddd)
<m> month of the year (mm)
<y> year (yyyy)

The geographical information used and created by WP4.

1.13.1 Block 1: available blue water

The maps and tables (in PCRaster format) are used as input for the PCRGLOBWB model to create maps and timeseries about the blue water availability in the case study sites and at the scale of Latin-America. All maps are also converted to (ArcGIS) files and stored in file geodatabases (fGDB's). The fGDB's were send to WP 3 and WP 6 for the WebGIS and DSS.

Case study sites

Static variables
The static variables in the table below are considered invariable over time (baseline, historic and future). All static maps for the case study sites reflect the baseline period applied in this project (2000-2010). All maps are raster files. The (ArcGIS) files are ordered in a file geodatabase, per case study site.

PCRaster, Model input, Static (and 1 monthly input)

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[4]	Temporal resolution
<C>dem.map	dem	Digital elevation model (m ASL)	I	static[5]
grad.map	grad	Slope gradient (m/m)	I	Static
glwd130m_ldd.map	glwd130m_ldd	Drainage network map	I	Static
kc_wat00.<d>	kc_wat00_<d>	composite crop factor for channels and wetlands or lakes (-)	I	monthly
fao30_ths30.map	fao30_ths30	saturated volumetric moisture content of the 1st soil layer (m3.m-3)	I	static
fao30_ths100.map	fao30_ths100	saturated volumetric moisture content of the 2nd soil layer (m3.m-3)	I	static
fao30_thr30.map	fao30_thr30	residual volumetric moisture content of the 1st soil layer (m3.m-3)	I	static
fao30_thr100.map	fao30_thr100	residual volumetric moisture content of the 2nd soil layer (m3.m-3)	I	static
fao30_ks30.map	fao30_ks30	saturated hydraulic conductivity of the 1st soil layer (m.day-1)	I	static
fao30_ks100.map	fao30_ks100	saturated hydraulic conductivity of the 2nd soil layer (m.day-1)	I	static
fao30_psis30.map	fao30_psis30	air entry value of the 1st soil layer (m) according to SWRC of Clapp & Hornberger (1978)	I	static
fao30_psis100.map	fao30_psis100	air entry value of the 2nd soil layer (m) according to SWRC of Clapp & Hornberger (1978)	I	static
fao30_beta30.map	fao30_beta30	Pore size distribution parameter of the 1st soil layer according to Clapp and Hornberger (1978)	I	static
fao30_beta100.map	fao30_beta100	Pore size distribution parameter of the 2nd soil layer according to Clapp and Hornberger (1978)	I	static
fao30_z1_permafrost.map	fao30_z1_permafrost	Depth of the 1st store (m)	I	static
fao30_z2_permafrost.map	fao30_z2_permafrost	Depth of the 2nd store (m)	I	static
fao30_sc1_permafrost.map	fao30_sc1_permafrost	total storage of 1st soil layer (m)	I	static

[4] Input (I) or Output (2) to the PCRGLOBWB model
[5] i.e. invariable over the period considered (baseline, historic or future)

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[4]	Temporal resolution
fao30_sc2_permafrost.map	fao30_sc2_permafrost	total storage of 2nd soil layer (m)	I	static
fao30_sc_permafrost.map	fao30_sc_permafrost	total storage of total soil profile (m)	I	static
minf_short_permafrost.map	minf_short_permafrost	ratio of min soil depth over average soil depth (-)	I	static
minf_tall_permafrost.map	minf_tall_permafrost	ratio of min soil depth over average soil depth (-)	I	static
maxf_short.map	maxf_short	ratio of max soil depth over average soil depth (-)	I	static
maxf_tall.map	maxf_tall	ratio of max soil depth over average soil depth (-)	I	static
rfrac1_short.map	rfrac1_short	root fraction 1st soil layer (of short vegetation types)	I	static
rfrac2_short.map	rfrac2_short	root fraction 2nd soil layer (of short vegetation types)	I	static
rfrac1_tall.map	rfrac1_tall	root fraction 1st soil layer (of tall vegetation types)	I	static
rfrac2_tall.map	rfrac2_tall	root fraction 2nd soil layer (of tall vegetation types)	I	static
fao30_p2imp_permafrost.map	fao30_p2imp_permafrost	fractional area where percolation to groundwater store is impeded (-)	I	static
globalalpha.map	globalalpha	recession coefficient for store 3 (day-1): drainage	I	static
specificyield.map	specificyield	specific yield for aquifer (-)	I	static

Crop and vegetation parameters
The crop and vegetation maps, used as input for the PCRaster model to make maps about the available blue water, differ for the baseline and future model run. These crop and vegetation maps are raster files. The (ArcGIS) files are ordered in a file geodatabase, per case study site.

PCRaster, Model input, Vegetation variables (monthly) Baseline and future

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[6]	Temporal resolution
cv_s0000.<d>	cv_s0000_<d>	fractional vegetation cover for short vegetation types (-)	I	monthly
cv_t0000.<d>	cv_t0000_<d>	fractional vegetation cover for tall vegetation types (-)	I	monthly
kc_s0000.<d>	kc_s0000_<d>	Crop factor for short vegetation types (-)	I	monthly
kc_t0000.<d>	kc_t0000_<d>	Crop factor for tall vegetation types (-)	I	monthly
smax_s00.<d>	smax_s00_<d>	maximum interception storage for short vegetation types (m)	I	monthly
smax_t00.<d>	smax_t00_<d>	maximum interception storage for tall vegetation types (m)	I	monthly
vegf_short.map	vegf_short	Subdivision of short and tall vegetation types	I	static
vegf_tall.map	vegf_tall	Subdivision of short and tall vegetation types	I	static

Climate variables
The climate variables used as input for the PCRGLOBWB model to make maps about the available blue water, differ for the baseline and future model run. These maps are raster files. The (ArcGIS) files are ordered in a file geodatabase, per case study site.

PCRaster, Model input, Climate variables (daily). The baseline file geodatabases contain the following maps:

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[7]	Temporal resolution
ra000000.<d>	<C>_Climate_<cc>_<y>_ra000000_<d>	Daily precipitation (m/d)	I	Daily
ta000000.<d>	<C>_Climate_<cc>_<y>_ta000000_<d>	Average daily temperature (deg C)	I	Daily
ev000000.<d>	<C>_Climate_<cc>_<y>_ev000000_<d>	Daily potential evapotranspiration (m/d)	I	daily

PCRaster, Model input, Climate variables (daily). The future file geodatabases contain maps with the names:

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[8]	Temporal resolution
ra000000.<d>	<C>_<cc>_<y>_ra000000_<d>	Daily precipitation (m/d)	I	Daily
ta000000.<d>	<C>_<cc>_<y>_ta000000_<d>	Average daily temperature (deg C)	I	Daily

[6] Input (I) or Output (2) to the PCRGLOBWB model
[7] Input (I) or Output (2) to the PCRGLOBWB model
[8] Input (I) or Output (2) to the PCRGLOBWB model

This work was funded by the COROADO project (www.coroado-project.eu) under the EU 7th Framework Programme

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[8]	Temporal resolution
ev000000.<d>	<C>_<cc>_<y>_ev000000_<d>	Daily potential evapotranspiration (m/d)	I	daily

PCRaster, Model output

The model output maps are raster files (of PCRaster format). The (ArcGIS) files are ordered in a file geodatabase, per case study site.

PCRaster, Model output

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[9]	Temporal resolution	Remarks
etot.map	<cc>_Annual_etot.map	Total evapotranspiration (m)	O	annual	Baseline (2000-2010) or climate change scenario (2040-2050)
qavg_year.map	<cc>_Annual_qavg_year.map	Average yearly channel discharge (m3.s-1)	O	annual	Baseline (2000-2010) or climate change scenario (2040-2050)
r3_avg.map	<cc>_Annual_r3_avg.map	average recharge to the third, groundwater store (m)	O	annual	Baseline (2000-2010) or climate change scenario (2040-2050)
stot.map	<cc>_Annual_stot.map	total active storage (km3)	O	Annual	Baseline (2000-2010) or climate change scenario (2040-2050)
stotavg.map	<cc>_Annual_stotavg.map	average soil storage (m)	O	annual	Baseline (2000-2010) or climate change scenario (2040-2050)
mean<m>.map	<cc>_Monthly_statistics_mean<m>.map	Mean monthly available blue water (m3.s-1)	O	Monthly	Baseline (2000-2010) or climate change scenario (2040-2050)
median<m>.map	<cc>_Monthly_statistics_median<m>.map	Median monthly available blue water (m3.s-1)	O	Monthly	Baseline (2000-2010) or climate change scenario (2040-2050)
minimum<m>.map	<cc>_Monthly_statistics_minimum<m>.map	Minimum monthly available blue water (m3.s-1)	O	Monthly	Baseline (2000-2010) or climate change scenario (2040-2050)
maximum<m>.map	<cc>_Monthly_statistics_maximum<m>.map	Maximum monthly available blue water (m3.s-1)	O	Monthly	Baseline (2000-2010) or climate change scenario (2040-2050)

[9] Input (I) or Output (2) to the PCRGLOBWB model

Latin America

Latin America, model input, static maps

Static input maps reflect conditions around the year 2000.

PCRGLOBWB model input, Static

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O [10]	Temporal resolution
clone_latinamerica_5min.map	LatinAmerica_clone_5min.map	Specifies the area of interest (clone). The map attributes are taken from this map.	I	static
LatinAmerica_HYDRO1K_ SlopeLength_05min.map	LatinAmerica_HYDRO1K_ SlopeLength_05min.map	length of the characteristic hill slope (m)	I	static
LatinAmerica_GTOPO_ SlopeGradient_05min.map	LatinAmerica_GTOPO_ SlopeGradient_05min.map	gradient of the characteristic hill slope (m/m)	I	static
LatinAmerica_DSMW_SoilDepth_ TopLayer_05min.map	LatinAmerica_DSMW_SoilDepth_ TopLayer_05min.map	thickness (m) of the first (top) soil layer of the model	I	static
LatinAmerica_DSMW_SoilDepth_ BottomLayer_05min.map	LatinAmerica_DSMW_SoilDepth_ BottomLayer_05min.map	thickness (m) of the second soil layer of the model	I	static
LatinAmerica_DSMW_ThetaSat_ TopLayer_05min.map	LatinAmerica_DSMW_ThetaSat_ TopLayer_05min.map	saturated volumetric moisture content (m3/m3) for the first (top) layer of the model	I	static
LatinAmerica_DSMW_ThetaSat_ BottomLayer_05min.map	LatinAmerica_DSMW_ThetaSat_ BottomLayer_05min.map	saturated volumetric moisture content (m3/m3) for second layer of the model	I	static
LatinAmerica_DSMW_ThetaRes_ TopLayer_05min.map	LatinAmerica_DSMW_ThetaRes_ TopLayer_05min.map	residual volumetric moisture content (m3/m3) for the first (top) layer of the model	I	static
LatinAmerica_DSMW_ThetaRes_ BottomLayer_05min.map	LatinAmerica_DSMW_ThetaRes_ BottomLayer_05min.map	residual volumetric moisture content (m3/m3) for the second layer of the model	I	static
LatinAmerica_DSMW_AirEntryValue_ TopLayer_05min.map	LatinAmerica_DSMW_AirEntryValue_ TopLayer_05min.map	air entry value (m) for the first (top) layer of the model according to the SWRC of Clapp & Hornberger (1978)	I	static
LatinAmerica_DSMW_AirEntryValue_ BottomLayer_05min.map	LatinAmerica_DSMW_AirEntryValue_ BottomLayer_05min.map	air entry value (m) for the second layer of the model according to the SWRC of Clapp & Hornberger (1978)	I	static
LatinAmerica_DSMW_ShapeFactor_ TopLayer_05min.map	LatinAmerica_DSMW_ShapeFactor_ TopLayer_05min.map	shape factor (beta, -) for the first (top) soil layer of the model according to the SWRC of Clapp & Hornberger (1978)	I	static
LatinAmerica_DSMW_ShapeFactor_ BottomLayer_05min.map	LatinAmerica_DSMW_ShapeFactor_ BottomLayer_05min.map	shape factor (beta, -) for the second soil layer of the model according to the SWRC of Clapp & Hornberger (1978)	I	static
LatinAmerica_DSMW_SatHydConduct_ TopLayer_05min.map	LatinAmerica_DSMW_SatHydConduct_ TopLayer_05min.map	saturated hydraulic conductivity (m/day) for the first (top) soil layer of the model	I	static
LatinAmerica_DSMW_SatHydConduct_ BottomLayer_05min.map	LatinAmerica_DSMW_SatHydConduct_ BottomLayer_05min.map	saturated hydraulic conductivity (m/day) for the second soil layer of the model	I	static
LatinAmerica_DSMW_ImpededDrainage_ ALL_05min.map	LatinAmerica_DSMW_ImpededDrainage_ALL_05min.map	fractional area (m2/m2) of the soil surface where percolation to the groundwater store is impeded	I	static
LatinAmerica_GLCC_**Short**Vegetation_ vegetationFraction_05min.map	LatinAmerica_GLCC_**Short**Vegetation_ vegetationFraction_05min.map	vegetation fraction (m2/m2) for each land cover type, all types summing to unity	I	static
LatinAmerica_GLCC_**Short**Vegetation_ rootFraction_TopLayer_05min.map	LatinAmerica_GLCC_**Short**Vegetation_ rootFraction_TopLayer_05min.map	fraction of total root volume (-) present in the first (top) soil layer of the model	I	static
LatinAmerica_GLCC_**Short**Vegetation_ rootFraction_BottomLayer_05min.map	LatinAmerica_GLCC_**Short**Vegetation_ rootFraction_BottomLayer_05min.map	fraction of total root volume (-) present in the second soil layer of the model	I	static

[10] Input (I) or Output (2) to the PCRGLOBWB model

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O [10]	Temporal resolution
LatinAmerica_GLCC_**Short**Vegetation_minWHCRatio_05min.map	LatinAmerica_GLCC_**Short**Vegetation_minWHCRatio_05min.map	ratio relating the minimum water holding capacity of the soil to the average water holding capacity which is computed on the basis of soil depth and maximum available pore space; used in the improvedArno scheme (Todini, 1996; Hagemann & Gates, 2003)	I	static
LatinAmerica_GLCC_**Short**Vegetation_arnoShapeFactor_05min.map	LatinAmerica_GLCC_**Short**Vegetation_arnoShapeFactor_05min.map	the shape factor describing the distribution of water holding capacity mentioned here above.	I	static
LatinAmerica_GLCC_**Tall**Vegetation_vegetationFraction_05min.map	LatinAmerica_GLCC_**Tall**Vegetation_vegetationFraction_05min.map	vegetation fraction (m2/m2) for each land cover type, all types summing to unity	I	static
LatinAmerica_GLCC_**Tall**Vegetation_rootFraction_TopLayer_05min.map	LatinAmerica_GLCC_**Tall**Vegetation_rootFraction_TopLayer_05min.map	fraction of total root volume (-) present in the first (top) soil layer of the model	I	static
LatinAmerica_GLCC_**Tall**Vegetation_rootFraction_BottomLayer_05min.map	LatinAmerica_GLCC_**Tall**Vegetation_rootFraction_BottomLayer_05min.map	fraction of total root volume (-) present in the second soil layer of the model	I	static
LatinAmerica_GLCC_**Tall**Vegetation_minWHCRatio_05min.map	LatinAmerica_GLCC_**Tall**Vegetation_minWHCRatio_05min.map	ratio relating the minimum water holding capacity of the soil to the average water holding capacity which is computed on the basis of soil depth and maximum available pore space; used in the improvedArno scheme (Todini, 1996; Hagemann & Gates, 2003)	I	static
LatinAmerica_GLCC_**Tall**Vegetation_arnoShapeFactor_05min.map	LatinAmerica_GLCC_**Tall**Vegetation_arnoShapeFactor_05min.map	the shape factor describing the distribution of water holding capacity mentioned here above.	I	static
LatinAmerica_GroundWaterRecession Coefficient_05min.map	LatinAmerica_GroundWaterRecession Coefficient_05min.map	groundwater recession coefficient (1/days)	I	static
LatinAmerica_GroundWaterSpecificYield_05min.map	LatinAmerica_GroundWaterSpecificYield_05min.map	groundwater specific yield (m/m)	I	static
LatinAmerica_Hydro1k_dzrel_%04_ 05min.map	LatinAmerica_Hydro1k_dzrel_%04_ 05min.map	relative elevation of the foodplain (m); requires 12 percentile values including 1, 5, 10, 20 ... 100%; can be provided as the root of PCRaster map or a netCDF file with the percentiles included as a separate dimension.	I	static
ldd_latinamerica_5min.map	LatinAmerica_ldd_5min.map	local drainage direction map in PCRaster format	I	static
LatinAmerica_FractionWater_05min.map	LatinAmerica_FractionWater_05min.map	fraction of the land mass in each cell occupied by surface freshwater (m2/m2)	I	static
LatinAmerica_Hydro1k_ChannelGradient_05min.map	LatinAmerica_Hydro1k_ChannelGradient_05min.map	gradient along the drainage network (m/m)	I	static
LatinAmerica_ChannelWidth_05min.map	LatinAmerica_ChannelWidth_05min.map	width of a characteristic rectangular channel (m)	I	static
LatinAmerica_ChannelDepth_05min.map	LatinAmerica_ChannelDepth_05min.map	depth of a characteristic rectangular channel (m)	I	static
LatinAmerica_GRAND_WaterBodiesID_ 05min.map	LatinAmerica_GRAND_WaterBodiesID_ 05min.map	map identifying contiguous water bodies by a unique ID	I	static
LatinAmerica_GRAND_WaterBodiesType_05min.map	LatinAmerica_GRAND_WaterBodiesType_05min.map	map representing the corresponding waterbody type; 0: channels; 1: lakes; 2: reservoirs.	I	static
LatinAmerica_GRAND_WaterBodiesOutlet_05min.map	LatinAmerica_GRAND_WaterBodiesOutlet_05min.map	map identifying a single outlet from lakes and reservoirs by their corresponding ID. Endorheic lakes have no outlet specified. Note that the outlets have to be positioned in a way that the local drainage direction map remains sound.	I	static
LatinAmerica_GRAND_ReservoirCapacity_05min.map	LatinAmerica_GRAND_ReservoirCapacity_05min.map	map with the total storage capacity of each identified reservoir (m3)	I	static

Latin America, model input, crop and vegetation parameter maps

The crop and vegetation maps, used as input for the PCRGLOBWB model to make maps about the available blue water. These crop and vegetation maps are raster files. The (ArcGIS) files are ordered in a file geodatabase.

PCRGLOBWB model input

File name (PCRaster format and model input)	Feature name (stored in a fGDB)	Description	I/O[11]	Temporal resolution
kc_s0000.<m>	LatinAmerica_kc_s0000_<m>	Crop coefficient for short vegetation in month # (-)	I	monthly
cv_s0000.<m>	LatinAmerica_cv_s0000_<m>	Cover fraction of short vegetation in month # (m2/m2)	I	monthly
smax_s00.<m>	LatinAmerica_smax_s00_<m>	Maximum interception storage of short vegetation in month # (m)	I	monthly
kc_t0000.<m>	LatinAmerica_kc_t0000_<m>	Crop coefficient for tall vegetation in month # (-)	I	monthly
cv_t0000. <m>	LatinAmerica_cv_t0000_<m>	Cover fraction of tall vegetation in month # (m2/m2)	I	monthly
smax_t00. <m>	LatinAmerica_smax_t00_<m>	Maximum interception storage of tall vegetation in month # (m)	I	monthly

Latin America, model input, Climate parameters (daily).

PCRGLOBWB model input

File name (NetCDF format and model input)	Feature name (stored in a fGDB)	Description	I/O[12]	Temporal resolution
crucorrected_meteo_latinamerica.tar.gz	-	Compressed files contains NetCDF files with the Daily precipitation (m/d), Average daily temperature (deg C) and Daily potential evapotranspiration (m/d) over the period 1958-2010.	I	monthly

1.13.2 Block 2: water demand

Water demand is approximated by water withdrawal.
Maps in this block are features stored, per study site, in a file geodatabase.

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[11] Input (I) or Output (2) to the PCRGLOBWB model
[12] Input (I) or Output (2) to the PCRGLOBWB model

Suquía River Basin, Argentina: Argentina_Water_demand.gdb

Feature name	Description	Temporal resolution	Remarks
GW demand_urban	Groundwater withdrawal from urban sector (m3/s). A single circle is located on the city of Córdoba (representing the total groundwater withdrawal of the city). No specific locations for water withdrawal/uptake points were identified.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Surface water demand_urban upper basin	Surface water withdrawal from cities located upstream the city of Córdoba (m3/s). A single point represents the water demand from all small towns located upstream, not being possible the identification of the exact withdrawal/uptake point.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Surface water demand_urban	Total surface water withdrawal for urban sector in the city of Córdoba (m3/s). A single point located on the city of Córdoba represents the total water demand for urban use.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
SW demand_urban (Los Molinos DWPP)	Surface water withdrawal from Los Molinos drinking water treatment plant for urban use (m3/s). Location of point corresponds to drinking water treatment plant.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
SW demand_urban (Suquía DWPP)	Surface water withdrawal from Suquía drinking water treatment plant for urban use (m3/s). Location of point corresponds to drinking water treatment plant.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
SW demand_irrigation zone	Surface water withdrawal from irrigated areas in the study site (m3/s). Two areas are identified: north and south. Location of points does not correspond to real surface water withdrawal points.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW demand_irrigation zone	Groundwater withdrawal from irrigated areas in the study site (m3/s). Two areas are identified: north and south. Location of points does not correspond to real groundwater withdrawal points.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
SW+GW demand_industry	Surface water and groundwater withdrawal from industrial sector in the study case (m3/s). It considers the whole withdrawal from in the study site and it is represented with a point located on the only industrial park identified in the area.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
SW demand_industry	Surface water withdrawal from industrial sector in the study case (m3/s). It considers the whole withdrawal from in the study site and it is represented with a point located on the only industrial park identified in the area.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW demand_industry	Groundwater withdrawal from industrial sector in the study case (m3/s). It considers the whole withdrawal from in the study site and it is represented with a point located on the only industrial park identified in the area.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012

Alto Tiête River Basin, Brazil: Brazil_Water_demand.gdb

Feature name	Description	Temporal resolution	Remarks
GW_demand sanitation	Groundwater demand for sanitation purposes (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW_demand industry	Groundwater demand for industrial final use (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW_demand sanit & ind	Groundwater demand for industrial and sanitation final use (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW_demand irrigation	Groundwater demand for irrigated agriculture final use (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW_demand mining	Groundwater demand for mining activitiesl final use (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW_demand public water supply	Groundwater demand for public water supply (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GW_demand trade & commerce	Groundwater demand for trade and commercel final use (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GE_OutorgaSubterranea	Groundwater demand for ALL different activities (m3/s). Points represent locations where there is groundwater withdrawal. The volume considered is obtained from VAZAO_M3_S field in the Attribute table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand sanitation	Locations for surface water withdrawal for sanitation purposes, all of them holding permit for water withdrawal. 11 water consumers identified in total. The Volume considered is obtained from DEMANDA field in the Attribute table. Information given in m3/s.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand irrigation	Locations for surface water withdrawal for irrigated agriculture, all of them holding permit for water withdrawal. 24 water consumers identified in total. The Volume considered is obtained from DEMANDA field in the Attribute table. Information given in m3/s.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand mining	Locations for surface water withdrawal for mining activities (holding permit for water withdrawal). 4 water consumers identified in total. The Volume considered is obtained from DEMANDA field in the Attribute table. Information given in m3/s.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand public supply	Locations for surface water withdrawal for public supply, all of them holding permit for water withdrawal. 28 water consumers identified in total. The Volume considered is obtained from DEMANDA field in the Attribute table. Information given in m3/s.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand ind. & ind./sanit.	Locations for surface water withdrawal for industrial and sanitary & industrial purposes, all of them holding permit for water withdrawal. 69 water consumers identified in total. The Volume considered is obtained from DEMANDA field in the Attribute table. Information given in m3/s.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012

Feature name	Description	Temporal resolution	Remarks
pumping_stations_waterdemand	Location of groundwater withdrawal and final users	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012

Copiapó River Basin, Chile: Chile_Water_demand.gdb

Feature name	Description	Temporal resolution	Remarks
Surface water demand_agriculture	Volume of surface water withdrawal for irrigated agriculture differentiating among different spatial sectors (1-6) (m3/s). The demand for irrigation is represented as a single volume (point) per spatial sector, since specific quantities per intake point were not available	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Groundwater demand_urban	Locations of groundwater withdrawal for urban sector (m3/s). Volume extracted from Q_Oto_m3_s field in Attribute Table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_C_wells_drinking_water_with_permits	Locations of groundwater withdrawal for urban sector (drinking water) (m3/s). Volume extracted from Q_Oto_m3_s field in Attribute Table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_C_wells_domestic_use_with_permits	Locations of groundwater withdrawal for urban sector (domestic use) (m3/s). Volume extracted from Q_Oto_m3_s field in Attribute Table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Groundwater demand_agriculture	Locations of groundwater withdrawal for irrigated agriculture sector (m3/s). Volume extracted from Q_Oto_m3_s field in Attribute Table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_C_wells_irrigation	General information about wells extracting water for irrigation (with and without permits)	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Groundwater demand_mining	Locations of groundwater withdrawal for mining activities (m3/s). Volume extracted from Q_Oto_m3_s field in Attribute Table.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_C_wells_domestic_use	General information about wells extracting water for domestic use (with and without permits)	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_C_wells_drinking_water	General information about wells extracting water for drinking water	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Pumping Wells	General information about pumping wells within the study case	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Secondary Irrigation Water Intakes	Location of surface water withdrawal points for irrigation (no volume is allocated to each location).	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Principal Irrigation Water Intakes	Location of surface water withdrawal points for irrigation (no volume is allocated to each location).	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012

Rio Bravo/Rio Grande River Basin, Mexico: Mexico_Water_demand.gdb

Feature name	Description	Temporal resolution	Remarks
Water demand_agriculture DR26	Surface water withdrawal from irrigated area in District 26, section 67 (m3/s). Location of point represents total volume in DR26.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand_agriculture DR25	Surface water withdrawal from irrigated areas in District 25, divided into sub-districts (m3/s). Location of points represents total volume for each sub-district within DR25.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_pumping_delivery_point_sect64-65_DR26	Pumping delivery points for DR26 (section 64 and 65) (m3/s)	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_pumping_delivery_point_sect66_DR26	Pumping delivery points for DR26 (section 66) (m3/s)	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
GGM_pumping_delivery_point_sect67_DR26	Pumping delivery points for DR26 (section 67) (m3/s)	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand_industries	Surface water withdrawal from industrial sector in the study case (m3/s).	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Water demand_urban	Surface water withdrawal from urban/domestic sector in the study case (m3/s). A single point is represented on each urban zone (specific locations for water withdrawal are not identified)	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012

1.13.3 Block 3: water stress index, model in- and output

The model in- and output maps are raster files (of PCRaster format).
The (ArcGIS) files (maps and tables) are ordered in two file geodatabases, per case study site; 1 with model input and 1 with model output

Case study sites

File name (PCRaster format)	Feature name (stored in a fGDB)	Explanation	I/O[13]	Temporal resolution	Remarks
<C>dem.map	<C>dem	Digital elevation model (m)	I	Static	
Agr_prop#.tbl	Agr_prop# (tbl)	Proportion of annual gross water demand for irrigation applied in month # (-)	I	monthly	No information available; assumed equal divisio annual irrigation demand over months with irrigation
all_extractionpointsID.map	all_extractionpointsID	IDs of water supply points; missing values at non wsp (-)	I	Static	

[13] Input (I) or Output (2) to the WSI map tool)

File name (PCRaster format)	Feature name (stored in a fGDB)	Explanation	I/O[13]	Temporal resolution	Remarks
all_extractionpointsID_nonmv.map	all_extractionpointsID_nonmv	IDs of water supply points; 0 at non wsp (-)	I	Static	
Catclone.map	Catclone	Mask of study site (-)	I	Static	
Env_zonesID.map Industr_zonesID.map Irrigation_zonesID.map Urban_zonesID.map	Env_zonesID Industr_zonesID Irrigation_zonesID Urban_zonesID	IDs of environmental, industrial, agricultural and urban zones for which water demand was specified	I	Static	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Grad.map	Grad	Slope gradient (m.m-1)	I	Static	
Mean01.map...mean012.map	Mean01...mean012	Mean monthly available blue water over period 2000-2010 (m3.s-1) (output from PCRGLOBWB model) (m3.s-1)	I (O)	Monthly	Output from PCRGLOBWB model So **NOT** in the fGDB's of WSI but in the fGDB's of Availbele_blue_water_Model_Results (Baseline; monthly statistics)
q_env<m>.map	q_env<m>	Environmental flow demand in month # (m3.s-1)	I	monthly	Only available for Suquia River Basin
Waterdemand_groundwat_sectors_agr.tbl Waterdemand_groundwat_sectors_industr.tbl Waterdemand_groundwat_sectors_urb.tbl	Waterdemand_groundwat_sectors_agr (tbl) Waterdemand_groundwat_sectors_industr (tbl) Waterdemand_groundwat_sectors_urb (tbl)	Annual gross water withdrawal from groundwater per agricultural, industrial or urban user unit (m3.s-1)	I	Annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Waterdemand_surfwat_sectors_agr.tbl Waterdemand_surfwat_sectors_industr.tbl Waterdemand_surfwat_sectors_urb.tbl	Waterdemand_surfwat_sectors_agr (tbl) Waterdemand_surfwat_sectors_industr (tbl) Waterdemand_surfwat_sectors_urb (tbl)	Annual gross water withdrawal from surface water per agricultural, industrial or urban user unit (m3.s-1)	I	Annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
Watersupplypoints.map	Watersupplypoints	IDs of water supply points (-)	I	static	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012
D_agr.map D_industr.map D_urban.map D_mining.map	<C>_WSI_Result_<cc>_D_agr <C>_WSI_Result_<cc>_D_industr <C>_WSI_Result_<cc>_D_urban <C>_WSI_Result_<cc>_D_mining	Annual gross water withdrawal in agricultural, industrial, urban or mining user units (m3.s-1)	O	Annual	
D_agr#.map	<C>_WSI_Result_<cc>_D_agr#	Gross agricultural water withdrawal in month # (m3.s-1)	O	monthly	
D_tot#.map	<C>_WSI_Result_<cc>_D_tot#	Gross total water withdrawal for agricultural, industrial, urban, environmental or mining use in month # (m3.s-1)	O	monthly	
D_wa#.map	<C>_WSI_Result_<cc>_D_wa#	Ratio of local water withdrawal-to-blue water availability in month # (-)	O	monthly	
Fricdist.map	<C>_WSI_Result_<cc>_Fricdist	Friction-distance from water supply point to destination due to distance	O	Static	
wsi_#.map	<C>_WSI_Result_<cc>_wsi_#	Water stress index based on factor set for friction-distance in month #, non-normalized	O	monthly	
wsi_#n.map	<C>_WSI_Result_<cc>_	Normalized water stress index based on factor set for friction-distance in month #	O	monthly	

1.13.4 Block 4: (waste)water supply points

Maps in this block are features stored, per study site, in a file geodatabase.

Suquía River Basin, Argentina: Argentina_Waste_water_supply.gdb

Layer name	Description	Temporal resolution	Remarks
Planta Potabilizadora Los Molinos	Drinking Water Treatment Plant	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
Planta Potabilizadora Suquía	Drinking Water Treatment Plant	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
WWTP_Argentina_revised	Wastewater treatment plants with information on treated wastewater volumes	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
Municipal WWTP	Location, treatment and effluent properties of Bajo Grande Wastewater Treatment Plant (exit)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
Potential pipe line connection	Potential pipe lines connecting wastewater producers (i.e. municipal wastewater treatment plants) and water consumers (i.e. urban/domestic users, irrigated agriculture areas, industries, etc.). These lines are drawn following road network (whenever available) and polygons in the area, avoiding crossing urban zones. Potential connections are based on proximity (distance), quantity and quality of effluents.	annual	Based on data from study sites (indicator spreadsheets and geoinformation) and Del 2.1; benchmark: 2010-2012

Alto Tiête River Basin, Brazil: Brazil_Waste_water_supply.gdb

Layer name	Description	Temporal resolution	Remarks
B_wwtp_and_users_point	Wastewater generators and reusers being part of existing WR&R schemes	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
B_Indu_points renamed to B_Industrial_ww_discharge_points_holing_permits	Locations for industrial wastewater discharge points holding permits (only industrial is considered, excluding sanitary/industrial)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
GGM_B_wwtp_ABC	Location of ABC WWTP with treatment and effluent properties (quantity, quality)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
GGM_B_wwtp_Barueri	Location of Barueri WWTP with treatment and effluent properties (quantity, quality)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
GGM_B_wwtp_ParqueNovoMundo	Location of Parque Novo Mundo WWTP with treatment and effluent properties (quantity, quality)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012

Layer name	Description	Temporal resolution	Remarks
GGM_B_wwtp_SaoMiguel	Location of Sao Miguel WWTP with treatment and effluent properties (quantity, quality)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
GGM_B_wwtp_Suzano	Location of Suzano WWTP with treatment and effluent properties (quantity, quality)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
GGM_LA_miner	Locations where there is wastewater discharge with permit from mining activities (m3/s)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
GGM_LA_industrial	Locations where there is industrial wastewater discharge with permit (m3/s)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
WWTP	Location of municipal wastewater treatment plants with treatment and effluent properties	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
Wastewater production (m3/s) Wastewater_production_m3_per_s	Locations for wastewater discharge from municipal WWTP and industries holding permits for wastewater discharge. 92 wastewater generators identified in total. The Volume considered is obtained from DEMANDA field in the Attribute table. Information given in m3/s.	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
WWTPs	Municipal WWTP being part of WR&R schemes with treatment and effluent properties	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
Pipe lines current WR&R schemes	Pipe lines of real WR&R schemes in the study site. Based on literature found: 1) WR&R scheme #1 AQUAPOLO http://www.weat.org/Presentations/2013_B13_RONCONI_AquapoloPresentationTexasWaterReuseConferenceclean.pdf 2) WR&R scheme #2 SABESP-1 Deliverable 2.1 (no real pipe line connection is shown) 3) WR&R scheme #3 SABESP-2 Deliverable 2.1 (no real pipe line connection is shown)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012

Copiapó River Basin, Chile: Chile_Waste_water_supply.gdb

Layer name	Description	Temporal resolution	Remarks
WWTP	Location of municipal wastewater treatment plants in the study site with treatment and effluent properties (quantity, quality)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
WW production_municipal WWTP	Volume of treated wastewater discharged from municipal WWTPs (m3/s)		

Rio Bravo/Rio Grande River Basin, Mexico

Layer name	Description	Temporal resolution	Remarks

Layer name	Description	Temporal resolution	Remarks
WW production_industrial_wwtp	Volume of wastewater discharged from industries in the study site (m3/s)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
Municipal WWTP point	Location of municipal wastewater treatment plants in the study site	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012
WW production_municipal_wwtp	Volume of wastewater discharged from municipal WWTPs (m3/s)	annual	Based on data from study sites (indicator spreadsheets and geoinformation), literature and Del 2.1; benchmark: 2010-2012

1.13.5 Block 5: potential wastewater demand points

Potential wastewater demand points include existing water users (see block 2 and urban, industrial and irrigated zones in each river basin[14]) and users of treated wastewater in existing WR&R schemes. The latter are only mapped for the study sites in Brazil and Mexico, since in the other sites no information is available on users of existing WR&R schemes, or WR&R schemes are absent. For all 4 case study sites, feature layers with potential pipe lines connecting wastewater producers and potential reusers are available.

Suquía River Basin, Argentina: Argentina_Potential_Waste_water_demand.gdb

Layer name	Description	Temporal resolution	Remarks
Potential pipe line connection	Potential pipe lines connecting wastewater producers (i.e. municipal wastewater treatment plants) and water consumers (i.e. urban/domestic users, irrigated agriculture areas, industries, etc.).	n.a.	These lines are drawn following road network (whenever available) and polygons in the area, avoiding crossing urban zones. Potential connections are based on proximity (distance), quantity and quality of effluents. UC proposed potential use for irrigated agriculture downstream of Cordobá city, but did not provide locations

Alto Tiête River Basin, Brazil: Brazil_Potential_Waste_water_demand.gdb

Layer name	Description	Temporal resolution	Remarks
GGM_B_WR&R_reusers	Reusers from existing WR&R schemes in the study sitew		
B_wwtp_and_users_point	Wastewater generators and reusers being part of existing WR&R schemes		
Potential pipe line connection	Potential pipe lines connecting wastewater producers (i.e. municipal and industrial wastewater treatment plants) and water consumers (i.e. urban/domestic users, irrigated agriculture areas, industries, etc.).	n.a.	These lines are drawn following road network and polygons in the area, avoiding crossing urban zones. Potential connections are based on proximity (distance), quantity and quality of effluents.

[14] Feature layers of urban, industrial and irrigated zones are available in the geoinformation database from WP4, but not listed here, since we assume these layers to be readily available from the WebGIS hosted by WP3.

Copiapó River Basin, Chile: Chile_Potential_Waste_water_demand.gdb

Layer name	Description	Temporal resolution	Remarks
Potential pipe line connection	Potential pipe lines connecting wastewater producers (i.e. municipal wastewater treatment plants) and water consumers (i.e. urban/domestic users, irrigated agriculture areas, industries, etc.).	n.a.	These lines are drawn following road network and polygons in the area, avoiding crossing urban zones. Potential connections are based on proximity (distance), quantity and quality of effluents.

Rio Bravo/Rio Grande River Basin, Mexico: Mexico_Potential_Waste_water_demand.gdb

Layer name	Description	Temporal resolution	Remarks
WR&R schemes (primary)	Location of WR&R schemes in the study site	annual	information about volume reused was mentioned as AVAILABLE, but not found
WR&R schemes (secondary)	Location of WR&R schemes in the study site, with volumes reused	annual	
Potential pipe line connection	Potential pipe lines connecting wastewater producers (i.e. municipal and industrial wastewater treatment plants) and water consumers (i.e. urban/domestic users, irrigated agriculture areas, industries, etc.).	n.a.	These lines are drawn following road network and polygons in the area, avoiding crossing urban zones. Potential connections are based on proximity (distance), quantity and quality of effluents.

1.14 Water quality standards in the COROADO study sites

This annex is delivered as a separate report and accompanying Excel sheet with an overview of water quality standards in the four COROADO study sites.