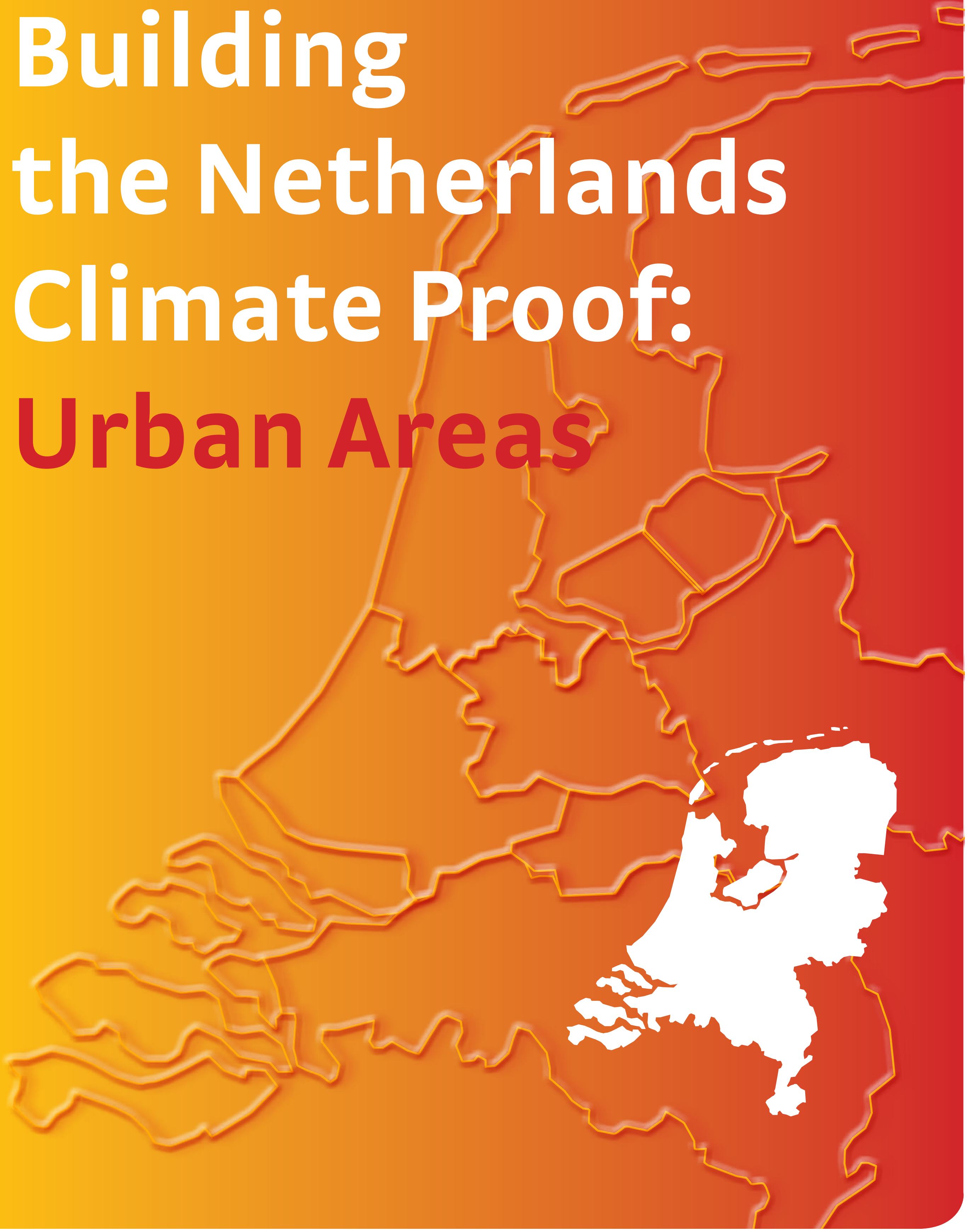
Building the Netherlands Climate Proof: Urban Areas



climate changes spatial planning

Knowledge for Climate

CLIMATE PROOF NETHERLANDS

Building the Netherlands Climate Proof: Urban Areas

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Deltares
Enabling Delta Life

UNESCO-IHE
Institute for Water Education

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Management samenvatting (NL)

Bevindingen

1. Inleiding

Nederland verstedelijkt in hoog tempo. Nu al wordt circa 20% van ons land ingenomen door stedelijk gebied en de verwachting is dat het aantal woonwijken, industrieterreinen, winkelcentra, kantorenparken, haventerreinen en dergelijke in de nabije toekomst nog verder zal toenemen. Het grootste deel van de inwoners van Nederland woont en werkt binnen de 'bebouwde kom". Het belangrijkste deel van de economische productie vindt er plaats. Ook is ons cultureel erfgoed daar geconcentreerd.

Nederlandse steden zijn kwetsbaar voor extreme weersomstandigheden. Dit heeft twee oorzaken. In de eerste plaats is de inrichting niet ontworpen op extreme omstandigheden. Wanneer die door klimaatverandering frequenter en extremer worden, dan blijkt dat de robuustheid van de stedelijke inrichting niet goed kan worden aangepast aan de veranderende omstandigheden. In de tweede plaats is de geofysische uitgangssituatie die we in Nederland kennen niet ideaal voor verstedelijking. We leven in een laagland dat gevoelig is voor overstromingen vanuit zee en/of vanuit de grote rivieren. Gradiënten zijn beperkt waardoor overtollig regenwater maar moeilijk is af te voeren. De bodem is er slap en nat, dus passen we onze bodem, het waterbeheer en onze bouwwerken daarop aan. Daar staat tegenover dat de vestigingsvoorwaarden in ons land gunstig zijn vanuit het oogpunt van handel, transport, infrastructuur, kennis, etc. maar dan moeten we de geofysische omstandigheden voldoende weten te beheersen.

Klimaatverandering heeft tot gevolg dat de weersomstandigheden veranderen, en dientengevolge ook de geofysische omstandigheden en de kwaliteit en veiligheid van onze woon- en werkomgeving. Klimaatverandering kan dus het vestigingsklimaat voor mensen en bedrijven negatief beïnvloeden, tenzij we in staat zijn om tijdig passende maatregelen te treffen. Centrale vragen voor deze maatschappelijke opgave zijn:

- Hoe beïnvloedt klimaatverandering de extreme weersomstandigheden en de geofysische omstandigheden in onze stedelijke gebieden?
- Hoe schadegevoelig zijn onze stedelijke gebieden voor die veranderingen? Welke plekken zijn gevoelig, welke minder gevoelig en waarom?
- Welke adaptatiemaatregelen kunnen we treffen om de negatieve gevolgen van klimaatverandering te beperken? Welke maatregelen zijn het meest zinvol? Op welk moment moeten we die treffen? En wie kan dat het beste doen?

Rond deze vraagstukken zijn vrijwel geen direct relevante en betrouwbare gegevens beschikbaar. Niet over de veranderingen in extreme weersomstandigheden in de stad.

Niet over de gevoeligheid; die is voor belangrijke onderdelen van het stedelijk systeem niet onderzocht. Veel potentiële schadeposten verborgen als algemene maatschappelijke kosten ten gevolge van slechter functioneren van economie en samenleving. Ook de effectiviteit van sommige aanpassingsmaatregelen behoeft nader onderzoek.

Gevolg van dit gebrek aan gegevens is dat we alleen met behulp van data mining een beeld kunnen afleiden van *relatieve* gevoeligheden en van *relatieve* kwetsbaarheden. Uit allerlei gegevensbestanden over landgebruik, bodem, maaiveldhoogte, gebouwen, wijktypologie enzovoorts zijn beelden afgeleid van de kwetsbaarheden van het stedelijk gebied. Dit is gedaan op basis van (1) de veranderende blootstelling, (2) de schadegevoeligheid en (3) het aanpassingsvermogen van de stedelijke omgeving. Vooral is gekeken naar allerlei harde adaptatiemaatregelen alsook naar de zachte maatregelen die van invloed zijn op de ruimtelijke ordening en de ruimtelijke inrichting. Maatregelen zonder ruimtelijke gevolgen zijn in deze studie buiten beschouwing gebleven.

Belangrijke vraag is ook vanaf wanneer aanpassingen nodig zijn om tijdig voorbereid te zijn op veranderde omstandigheden. Moeten we nu al rekening gaan houden met klimaatverandering of is dat pas relevant na bijvoorbeeld 2025? Ook is evident dat meekoppeling van klimaatadaptatie met stedelijke herstructurering voordelen heeft. Maar moeten we dan nu al in actie komen? Klimaatadaptatie is dus niet enkel een vraagstuk in ruimte maar zeker ook in tijd. En wie moet er in actie komen? De Rijksoverheid, provincies, gemeenten, waterschappen, de burgers en bedrijven zelf of de EU, om in Europa een *level playing field* te waarborgen?

2. Kwetsbaarheid van het stedelijk systeem

Klimaatverandering zal leiden tot zeespiegelstijging, meer neerslag, tot meer en zwaardere buien, meer extreme afvoeren in de grote rivieren, hogere temperaturen, meer verdamping en langere perioden van droogte. De effecten daarvan komen terug in de stedelijke gebieden, deels versterkt doordat de stad ”van nature” al warmer is dan het ommeland. De blootstelling van onze steden en dorpen aan extreme weersomstandigheden zal naar verwachting toenemen, zowel wat betreft de kans van optreden als de ernst van de blootstelling. De mate waarin dat zal gebeuren laat zich echter nog niet goed voorspellen, mede omdat we de versterkte doorwerking van klimaatverandering in de stedelijke omgeving niet kunnen kwantificeren.

De toename van de **kwetsbaarheid** van stedelijke gebieden wordt niet alleen veroorzaakt door verandering van het klimaat, maar zeker ook door stedelijke groei. Nieuwbouw op laaggelegen gronden, toename van de industriële productiviteit, verdichting van functies en verouderende infrastructuur zijn ontwikkelingen waardoor de kwetsbaarheid wordt vergroot, ook zonder klimaatsverandering. In deze studie nemen we de bestaande stad als uitgangspunt en toetsen we welke invloed het klimaat hier op heeft, nu en in de toekomst.

Onze steden zijn de resultante van een eeuwenoud groeiproces, met een belangrijke versnelling na de Tweede Wereldoorlog. Veel van de gebouwen, huizen, straten en pleinen zijn al vele decennia geleden gebouwd of aangelegd. Grote delen van de stad zijn dus ingericht volgens de criteria van toen; ze voldoen eigenlijk niet aan de wensen en behoeften van vandaag, maar aanpassing is ingrijpend en duur. Grootschalige herinrichtingen vinden hooguit eenmaal per 50–100 jaar plaats. Het aanpassingsvermogen van een stedelijke omgeving is daardoor beperkt.

Een inrichting “volgens de criteria van toen” betekent ook “naar de klimatologische omstandigheden van toen”. En natuurlijk ook volgens de comforteisen van toen en met de technieken van toen. Een verandering in de klimatologische blootstelling kan dus tot gevolg hebben dat we de waterhuishouding en de bodem in de stad niet langer in voldoende mate kunnen beheersen. Extremen in neerslag, droogte of hitte kunnen meer schade aanrichten dan waar in het verleden mee gerekend was. Of – nog sluipender – de veranderde blootstelling kan tot gevolg hebben dat het grondwaterregime verandert en dat de bodem sneller gaat zetten of inklinken, waardoor extra schade ontstaat aan gebouwen, wegen, spoorwegen, tunnels, kabels en leidingen. Hogere extreme temperaturen hebben tot gevolg dat het comfort van het binnen- en buitenklimaat afneemt. Daardoor zien we een snelle opkomst van de airconditioning in ons land. Daarnaast is de openbare ruimte in steden niet ingericht op extreme hitte.

De mate waarin schade kan ontstaan aan de stedelijke inrichting en haar bewoners hangt af van de schadegevoeligheid van de verschillende onderdelen van het stedelijk systeem. En die gevoeligheid verschilt natuurlijk voor wateroverlast, voor overstromingen, voor droogte en voor hitte. De schade die een veranderde blootstelling tot gevolg heeft is sterk afhankelijk van de lokale omstandigheden, tot op het detailniveau van de woning en haar bewoners.

De schade die extreme omstandigheden kunnen aanrichten hangt niet alleen af van de blootstelling, de schadegevoeligheid en het aanpassingsvermogen. We kunnen die schade ook inperken door verbetering van het **incasseringsvermogen** (coping capacity) en het **herstelvermogen**. Het incasseringsvermogen is erop gericht de schade tijdens zo’n extreme situatie zo beperkt mogelijk te houden. Het herstelvermogen is erop gericht de samenleving en de economie zo spoedig mogelijk na de extreme omstandigheden weer normaal te laten draaien. De gevolgschade van rampen is vaak vele malen groter dan de directe schade, dus is herstelcapaciteit van het grootste belang. Het incasseringsvermogen en het herstelvermogen hebben echter niet of nauwelijks ruimtelijke gevolgen – met uitzondering van de capaciteit van vluchtroutes en van aanvoerroutes voor hulp- en herstelgoederen. Daarom zijn deze beide vermogens hier niet nader onderzocht.

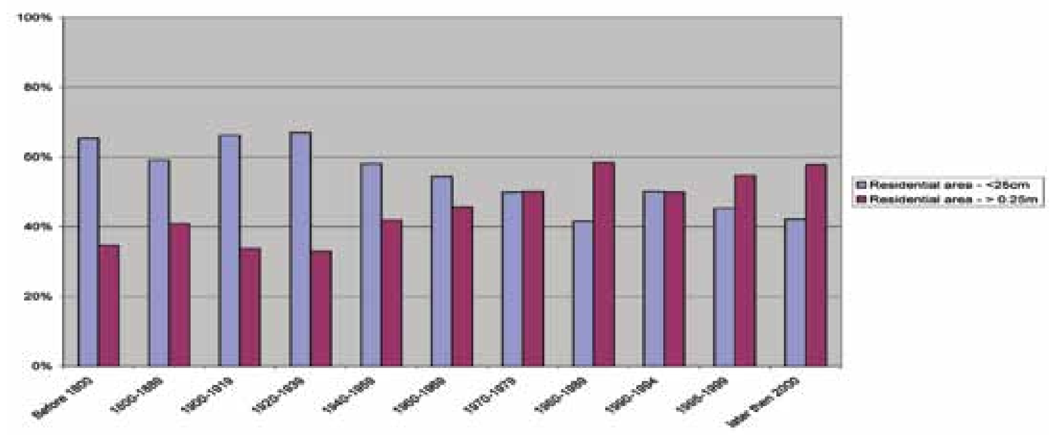
2.1. Overstromingsgevaar

Grote delen van ons land staan bloot aan overstromingsgevaar vanuit zee, vanuit het hoofdwatersysteem of vanuit secundaire wateren, en we doen er alles aan om dergelijke overstromingen te voorkomen. Keringen worden steeds getoetst en verder versterkt wanneer blijkt dat deze niet meer voldoen aan de hoge veiligheidsnormen. De kans op een overstroming van bebouwd gebied – met uitzondering van de buitendijkse gebieden – neemt dus bij klimaatverandering niet toe. Maar de mate van blootstelling en de schadegevoeligheid nemen wel toe. Daarom wordt in het Nationaal Water Plan gekozen voor een meerlaagse veiligheidsbenadering. In aanvulling op de preventieve maatregelen zal de komende jaren meer aandacht worden geschonken aan gevolgen-beperkende maatregelen in de sfeer van de ruimtelijke ordening en inrichting.

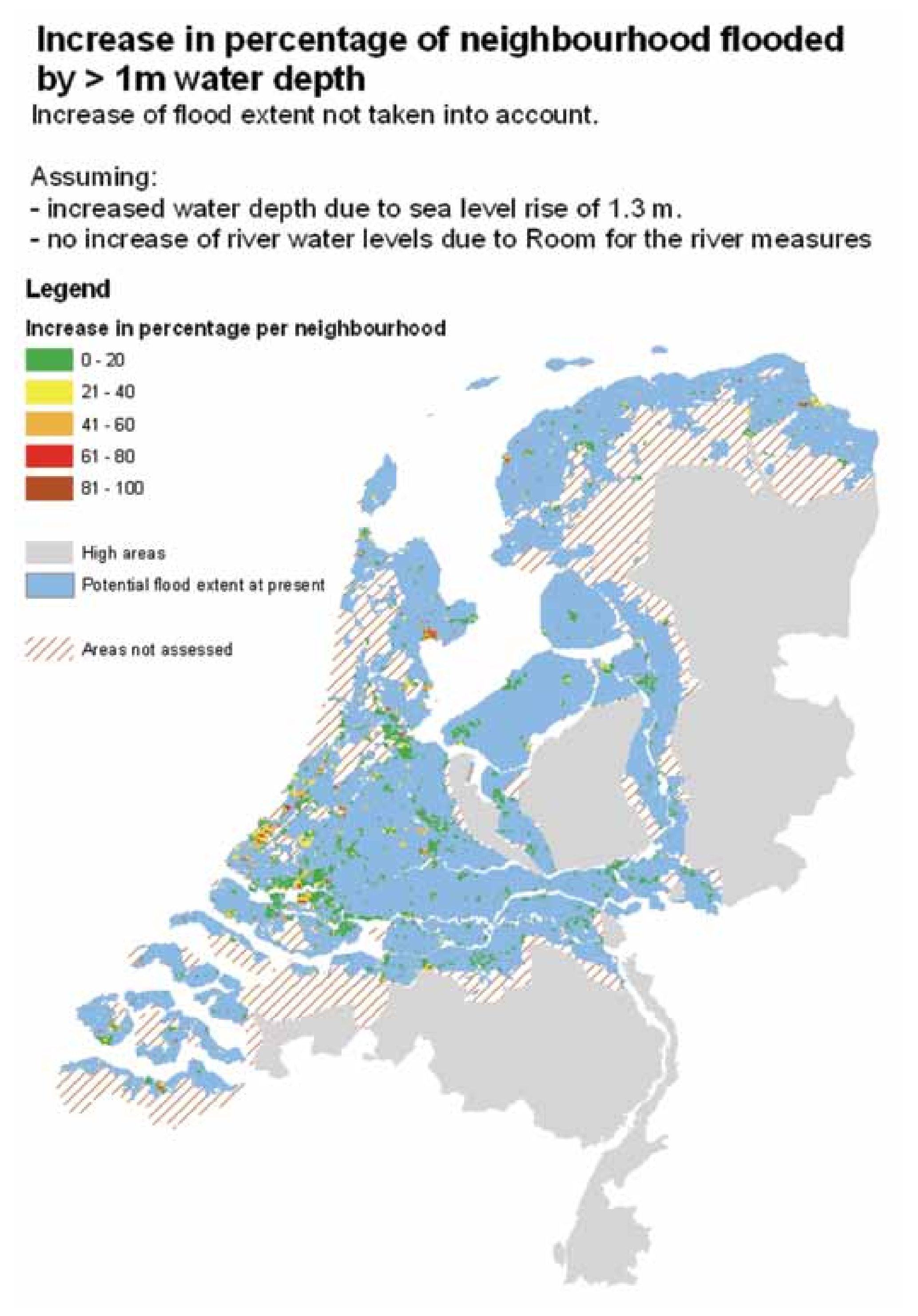
Blootstelling

Als gevolg van klimaatverandering en zeespiegelstijging wordt voorzien dat de waterdiepte, de omvang van het overstroomd gebied en de overstromingsduur toe zullen nemen. Een analyse van de blootstelling van de bebouwde gebieden aan overstromingsgevaar levert het volgende beeld op:

- Bouwen in gebied dat door overstromingen wordt bedreigd is van alle tijden. 30 % van de woongebieden ligt in gebieden die zijn blootgesteld aan overstromingsgevaar.
- Bij een forse zeespiegelstijging zal de blootstelling vooral toenemen voor steden in de provincies Noord- en Zuid-Holland, Zeeland, Friesland en Groningen.
- Vanaf de na-oorlogse jaren is een verschuiving te zien naar méér bouwen in gebieden met overstromingsgevaar (zie figuur 1).
- Ons cultureel erfgoed ligt voor 80 % in gebieden die niet of nauwelijks door het water worden bedreigd.
- Door klimaatverandering kan een toename ontstaan van het stedelijk gebied dat kan overstromen. Dit als gevolg van het overstromen van gebieden beschermd door secundaire dijken waarvan voor de huidige situatie aangenomen wordt dat deze niet zullen overstromen. Ook de mate van overstromingen kan toenemen als gevolg van een verwachte toename in waterdiepte (zie figuur 2).
- Bepaalde stedelijke gebieden in west Nederland worden niet zozeer bedreigd door overstromingen vanuit het hoofdwatersysteem maar zijn wel blootgesteld aan overstromingsgevaar door het falen van secundaire keringen rond boezemwateren, ringvaarten en andere hoofdwatergangen.



Figuur 1

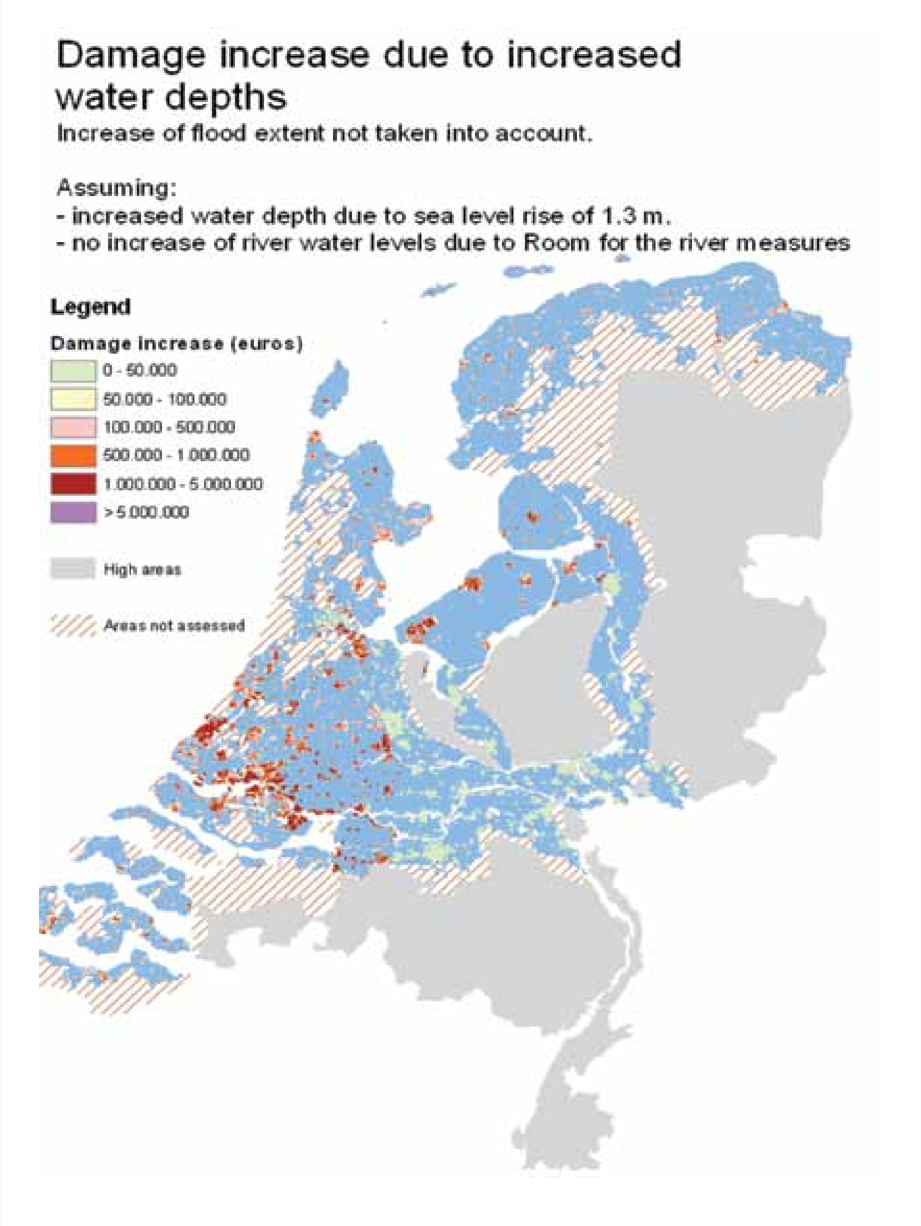

Increase in percentage of neighbourhood flooded by > 1m water depth
Increase of flood extent not taken into account.
Assuming:
- increased water depth due to sea level rise of 1.3 m.
- no increase of river water levels due to Room for the river measures
Legend
Increase in percentage per neighbourhood
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
High areas
Potential flood extent at present
Areas not assessed

Figuur 2

Gevoeligheid

Van de schadegevoeligheid van het stedelijk gebied als gevolg van overstromingen vanuit zee en vanuit de grote rivieren is nog slechts een gefragmenteerd beeld. Veel is bekend over de directe en indirecte economische schade per dijkring en over de kans op dodelijke slachtoffers. Een indicatie van de toename van schade voor het stedelijke gebied per cel van 100 x 100 m als gevolg van de een overstroming na een extreme zeespiegelstijging is hier aangegeven (zie figuur 3).

De gevoeligheid voor slachtoffers is het grootst langs de grote rivieren, zeker in het overgangsgebied van rivier en zee waar de voorspellingstijden kleiner zijn. Een toename in slachtoffers wordt voorzien voor de grotere dijkringen langs de kust als gevolg van een toenemende overstromingsdiepte en overstromingsoppervlak. Deze gebieden kunnen onder de huidige omstandigheden niet volledig geëvacueerd worden.



Figuur 3

Kwetsbaarheid

Omdat aangenomen wordt dat de *kans* op een overstroming niet toe zal nemen, wordt de toename van de kwetsbaarheid door overstroming als gevolg van klimaatverandering bepaald door de mate van blootstelling en de schadegevoeligheid. Er zijn drie insteken voor het reduceren van de kwetsbaarheid (schade en slachtoffers) door maatregelen in de sfeer van de ruimtelijke ordening en inrichting:

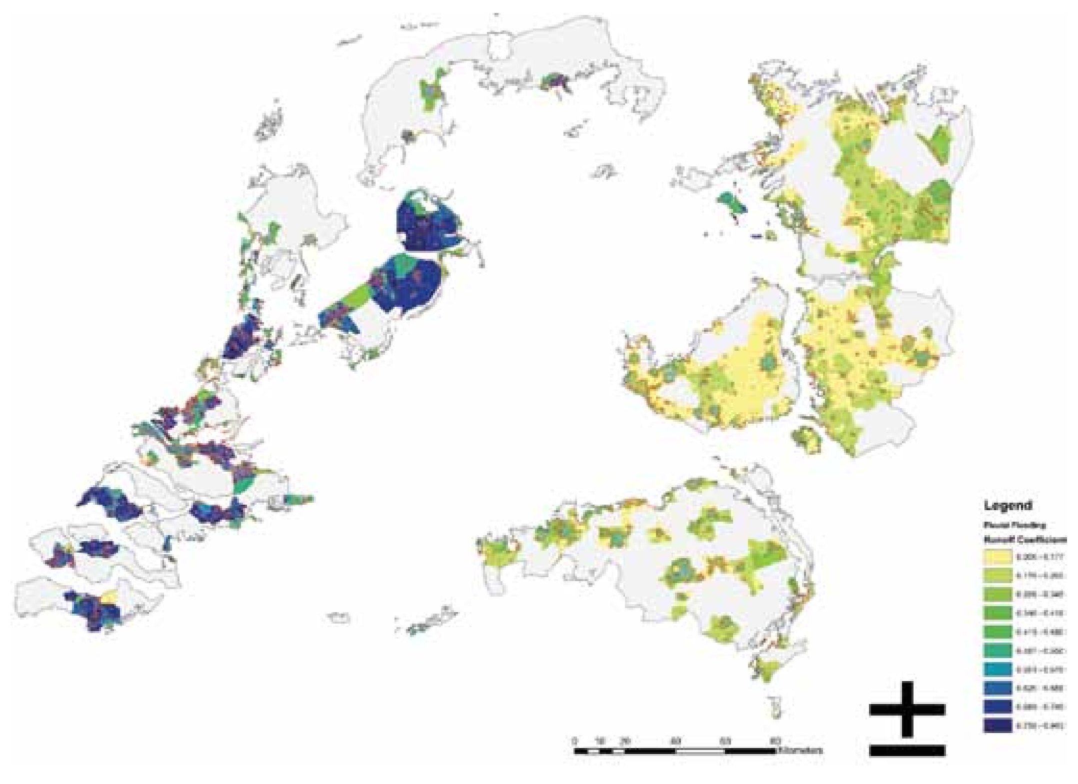
1. Het *reduceren van de blootstelling* door de instroom van water te beperken. Dit kan bereikt worden met bijvoorbeeld doorbraakvrije dijken en compartimentering.
2. Het *reduceren van de gevoeligheid* door zonering en bouwvoorschriften. Maatregelen in deze sfeer zijn onder andere locatiekeuze (zonering), verhogen van het maaiveldniveau, maatregelen aan de constructie en de inrichting van gebouwen, wegen, netwerken (elektriciteit, telecommunicatie, gas, water) en andere kwetsbare objecten. Maatregelen zijn niet alleen gericht op het voorkómen van schade door het water zelf, maar ook door (grond)waterverontreiniging, inclusief zout- en verziltingsschade).
3. *Reduceren van de gevoeligheid* met inrichtingsmaatregelen ter ondersteuning van de crisis management. Hierbij is te denken aan maatregelen gericht op de bescherming van vitale infrastructuur of op het faciliteren voor horizontale en/of verticale evacuatie.

2.2. Wateroverlast (water op straat)

Blootstelling

Als gevolg van klimaatverandering wordt verwacht dat zomerse buien in Nederland een grotere intensiteit krijgen. In stedelijke gebieden komt een groot deel hiervan direct tot afvoer. Door de aanwezigheid van veel verhard oppervlakte heeft slechts een klein deel de kans om in de bodem te infiltreren. Verdichting versterkt dit effect. Hierdoor zal de afvoer in de toekomst toenemen op plaatsen waar deze al het hoogste was.

Figuur 4 laat zien dat hierin een verschil is waar te nemen tussen gebieden op klei/veen in het westen en gebieden op zand in het oosten van Nederland. Voor een gematigde bui met dezelfde intensiteit zijn in gebieden met een klei/veen ondergrond verhoogde afvoer pieken waar te nemen



Figuur 4

in vergelijking met gebieden op zand. Dit leidt tot een verhoogde blootstelling aan regenwateroverlast in deze gebieden. Voor gematigde neerslag is er geen relatie gevonden tussen stedelijke typologieën en blootstelling voor wateroverlast. Verrassend genoeg is dit ook niet het geval voor extreme neerslagbuien, zelfs niet op bedrijventerreinen. Stedelijke centra vormen de uitzondering op de regel: hier is een nagenoeg uniforme relatie tussen het af te voeren water en de neerslag intensiteit.

Het verminderen van de afstand tot open water is gunstig voor het tegengaan van water op straat. Dit pleit voor het realiseren van een fijnmazig netwerk van open water en drainage systemen in stedelijk gebied.

Wateroverlast komt bovenal tot uiting in locaal laag gelegen plaatsen. Figuur 5, met Delft als voorbeeld, laat zien dat deze random zijn verspreid in de stad. Vanwege de 'vlakke' morfologie van Nederlandse steden zijn de inundaties die door regenwater te verwachten zijn, veelal beperkt tot diepten van < 0,20m. 'Flashfloods', zoals in de zomer van 2009 zijn opgetreden Zuid-Frankrijk en Istanbul, zijn derhalve in Nederland niet aan de orde. Zeer locaal kunnen grotere inundatiedieptes voorkomen.

Figuur 5

Gevoeligheid

De gevoeligheid van steden voor regenwateroverlast komt voor een belangrijk deel tot uitdrukking in een groot aantal 'kleine' schadegevallen door ondergelopen kelders en schoonmaakkosten voor de begane grond. Daarnaast treedt er bij zware buien veel indirecte schade op vanwege de gevoeligheid van infrastructuur (ondergelopen tunnels / hoofdontsluitingswegen). Op dit moment is er geen methode beschikbaar waarmee deze op een accurate manier is te kwantificeren. De blootstelling geldt dus als belangrijkste eenduidige parameter voor het bepalen van kwetsbaarheid voor regenwateroverlast.

Kwetsbaarheid

De kwetsbaarheid van het stedelijk gebied kan dus worden beperkt door een vergroting van de retentie- en afvoercapaciteit van het afvoersysteem, zeker op die laagstgelegen punten. Door meer berging op straat mogelijk te maken kan het risico van wateroverlast al worden beperkt. Bovendien is op te merken dat de afvoercapaciteit van de riolering in Nederland in het algemeen beperkt is, want gebaseerd op ons milde klimaat. Een toename van de kans op zeer zware buien zou ondervangen kunnen worden door het aanbrengen van een iets grotere redundantie in de capaciteit van de regenwaterafvoer.

2.3. Wateroverlast (grondwater)

Door de toename van de totale hoeveelheid neerslag, zal de ondiepe grondwaterstand structureel hoger worden, met uitzondering van de zomer en de vroege herfst. Ook de toename van de hoeveelheid extreme buien kan leiden tot het vaker optreden van hoge grondwaterstanden. Langs de rivieren stijgt bij hogere rivierafvoeren de stijghoogte in het eerste watervoerende pakket waardoor ook de ondiepe grondwaterstand in stedelijk gebied direct langs de rivier wordt verhoogd.

Stedelijke functies die gevoelig zijn voor te hoge grondwaterstanden (grondwateroverlast) zijn dus kwetsbaar voor de veranderingen van het klimaat. Overigens zijn andere processen zoals ingrepen in het watersysteem, bodemdaling en (het stopzetten van) grondwaterwinningen eveneens van invloed op de grondwaterstanden.

Blootstelling

Als het verschil tussen de grondwaterstand en het maaiveld (de ontwateringsdiepte) geringer is dan 0,7 m, dan wordt een gebied geclassificeerd als 'drainage afhankelijk'. In de regel zal kunstmatige drainage nodig zijn om grondwateroverlast in die gebieden tegen te gaan. Drainageonafhankelijke gebieden worden in de regel voldoende ontwaterd door het omringende oppervlaktewater. Het westen van Nederland kent over het algemeen hoge grondwaterstanden en er treedt in veel stadwijken onder de huidige omstandigheden grondwateroverlast op. Hoewel de grondwaterstanden op de hogere zandgronden in het oosten en zuiden van Nederland in de regel lager zijn, kan daar in bebouwde gebieden in de beekdalen ook sprake zijn van grondwateroverlast.

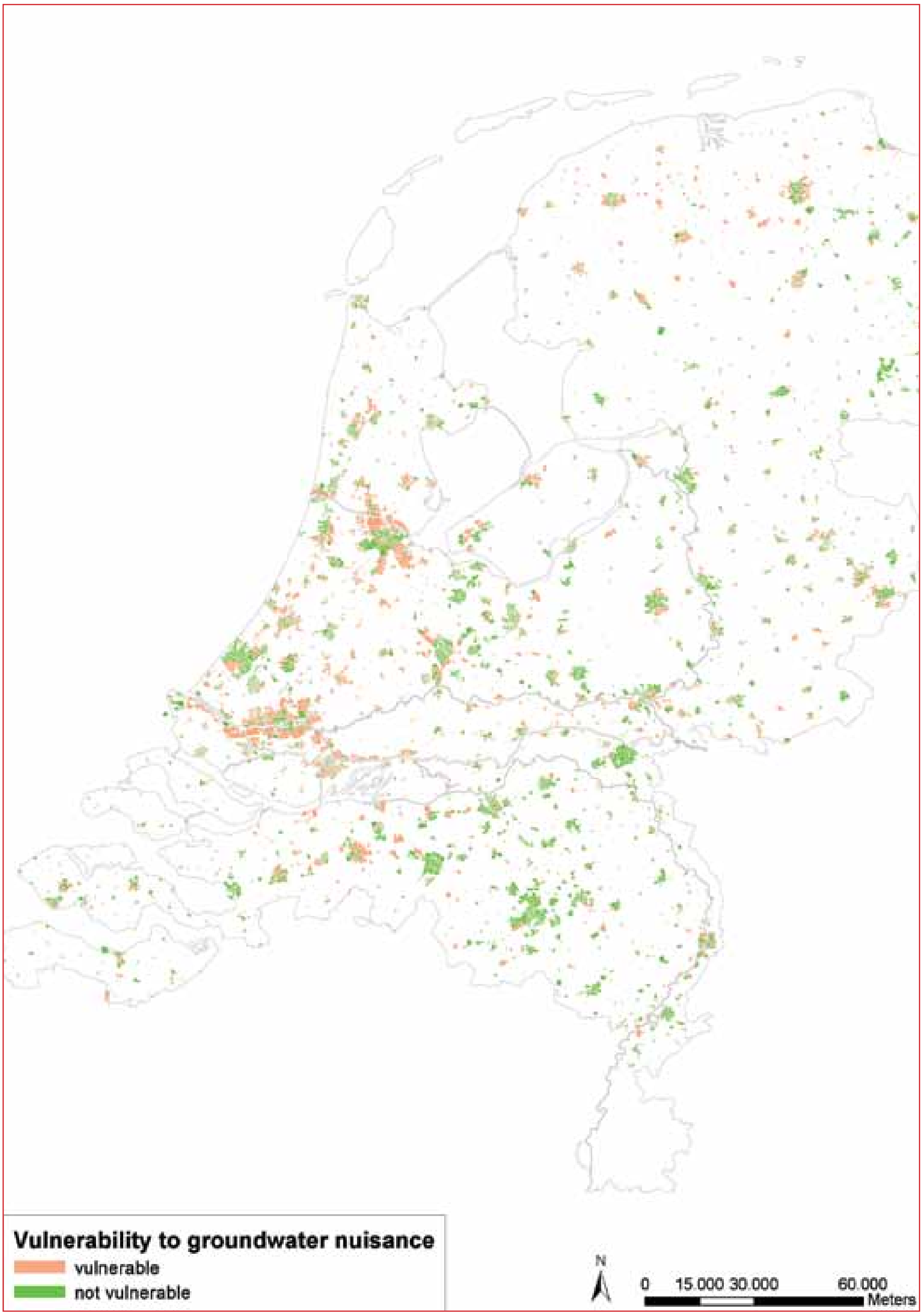
De toename van de neerslag zorgt voor een toename van de omvang en de duur van optredende grondwateroverlast. Gebieden die nu nog niet kampen met grondwateroverlast zullen daar in de toekomst mogelijk wel mee te maken krijgen. In gebieden waarin nu al grondwateroverlast optreedt zal dit intensiveren. Het areaal stedelijk gebied dat kwetsbaar is voor grondwateroverlast zal door de toegenomen belasting groeien met 7% tot 14%.
Het verminderen van de afstand tot open water of (ondergrondse) drainage systemen verhoogd de mogelijkheden van het water systeem om grondwateroverlast tegen te gaan. Dit pleit eveneens voor het realiseren van een fijnmazig netwerk van open water en drainage systemen in stedelijk gebied.

Gevoeligheid

Met name bebouwing van voor 1960, vervaardigd met houten begane grondvloer en kruipruimte, en stedelijk groen (vooral bomen) zijn gevoelig voor grondwateroverlast. Bebouwing van na 1960 is eveneens gevoelig omdat de vanaf toen gebruikelijke betonnen begane grond vloer vrijwel nooit water- en dampdicht is (kruipruimteluik, leidingdoorvoeren). Vanaf de jaren '80 is men weliswaar meer drainage in woongebieden gaan aanleggen, maar omdat het onderhoud nogal eens ontbreekt komen toch veel klachten en schade voor. Belangrijkste probleem is dat vochtoverlast in de woning kan leiden tot een forse toename van het aantal COPD-klachten (chronische longaandoeningen), naast rottende houten vloeren, schimmelend behang, muffe aanrechtkastjes en dergelijke. Wegen zijn in de regel minder gevoelig voor te hoge grondwaterstanden, behalve bij opvriezing.

Kwetsbaarheid

De helft van het stedelijke gebied blijkt enigszins tot sterk kwetsbaar voor grondwateroverlast omdat ze (a) worden blootgesteld aan hoge grondwaterstanden en (b) een functie hebben die daarvoor gevoelig is (zie figuur 6). Ook is meer dan de helft van het stedelijke groen enigszins tot sterk kwetsbaar voor grondwateroverlast. Wegen zijn minder kwetsbaar, omdat ze minder gevoelig zijn maar ook omdat slechts 17% van de wegen wordt blootgesteld aan hoge grondwaterstanden.


Vulnerability to groundwater nuisance
vulnerable
not vulnerable
N
0
15.000
30.000
60.000
Meters

Figuur 6

Over het algemeen zijn het vooral de lager gelegen, later gebouwde, wijken rondom het stadcentrum die kwetsbaar zijn voor grondwateroverlast. Er zijn overigens genoeg low-regret maatregelen voor het tegengaan van grondwateroverlast in bestaand stedelijk gebied die men mee kan koppelen met reguliere renovatie en herontwikkeling.

Zowel op hoge zandgronden als in laaggelegen klei en veen gebieden komt grondwateroverlast voor. Er is geen bijzondere relatie tussen het voorkomen van grondwateroverlast en de regionale geografische ligging van een stadswijk. Lokale omstandigheden alsook factoren als achterstallig onderhoud en verkeerde keuzes in het ontwerp in het watersysteem, zijn veel bepalender.

Na WOII is er structureel meer gebouwd in drainage afhankelijk gebied dan in drainage onafhankelijk gebied. Deze trend zet zich ook in de nabije toekomst door. Er zijn ruim voldoende maatregelen en bouwmethodes beschikbaar om nieuwbouw wijken (grond)waterrobuust aan te leggen. Het is nodig dat planontwikkelaars en het bevoegde gezag ook daadwerkelijk kiest voor een klimaatsrobuust ontwerp van de nieuwbouw gebieden. Het feit dat 84% van de nu geplande nieuwbouw in drainageafhankelijk gebied zal worden aangelegd, onderstreep de noodzaak hiervan.

2.4. Droogte

De toenemende droogte kan invloed hebben op verschillende stedelijke functies. Historische gebouwen in veen- en kleigebieden zijn in het bijzonder gevoelig voor droogte, maar ook groenvoorzieningen en ondergrondse infrastructuur kunnen schade oplopen. Verder kan de droogte ongunstig zijn voor de waterkwaliteit van het stedelijke watersysteem. In deze studie is daar geen onderzoek naar verricht.

Blootstelling

De schade aan historische gebouwen in veen- en kleigebieden is direct gerelateerd aan de verlaging van de grondwaterstand, door het droogvallen van de in het verleden toegepaste houten paalfundering. Het periodiek droogvallen van de houten palen zorg ervoor dat schimmels het hout kunnen aantasten en de paalkop kan gaan rotten. Dit leidt tot schade aan de bebouwing. Om een goed inzicht te krijgen in de kans op schade door deze paalrot is inzicht nodig in zowel de grondwaterdynamiek in de huidige en toekomstige situatie alsook het aanlegniveau van de houten paalfundering. Dit vergt een zeer uitgebreide inventarisatie en analyse van informatie die versnippert over vele instanties aanwezig is.

Het verlagen van de grondwaterstand heeft bovendien een indirect effect, namelijk dat het bodemdalingsproces dat overigens van nature optreedt in West en Noord-Nederland, wordt versneld. Daling van het maaiveld kan leiden tot schade aan bomen en aan gebouwen gefundeerd ‘op staal’ (niet gefundeerd op funderingspalen maar direct op de klei of veenbodem). Er is nog weinig bekend over de relatie tussen droogte en het optreden van versnelde zetting van de ondergrond. Ook stedelijke groenvoorzieningen en bomen kunnen schade oplopen door droogte.

Om de ongewenste effecten van droogte tegen te gaan zal het in de toekomst steeds vaker noodzakelijk zijn om water te kunnen aanvoeren in het stedelijke gebied. Ook voor het tegengaan van droogte biedt een fijnmazig netwerk van open water en infiltratievoorzieningen de beste mogelijkheid om water optimaal aan te voeren en te verdelen in het stedelijke gebied.

Gevoeligheid

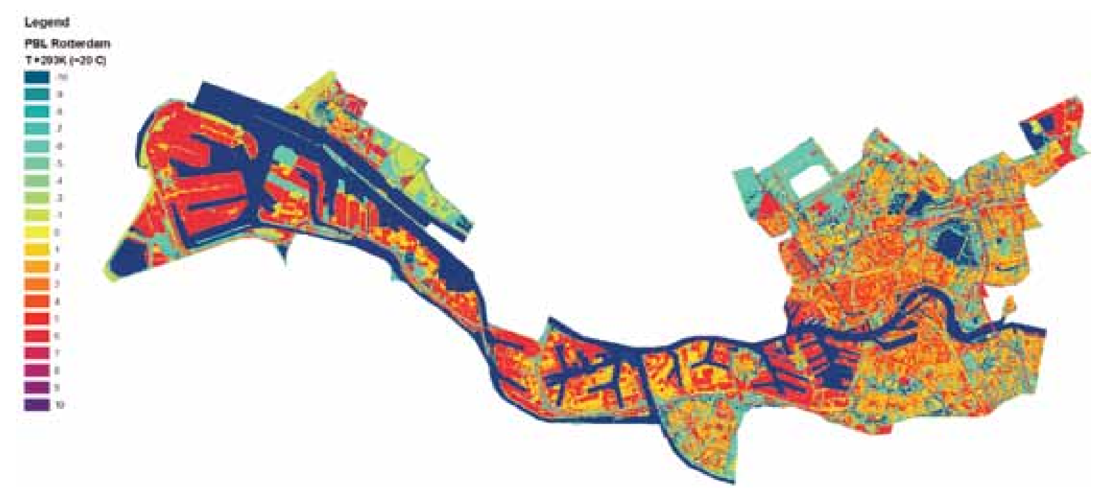
Door ontwatering klinken veen en kleilagen in de ondergrond in, waardoor het maaiveld zet. Veel bebouwing in veen- en kleigebieden staat daarom op palen om ervoor te zorgen dat door zetting van het maaiveld de bebouwing geen schade oploopt. Tot en met de jaren ’50 is gebruik gemaakt van houten funderingspalen, die gevoelig zijn voor periodieke droogstand. Recentere bebouwing is gefundeerd op betonnen palen die niet gevoelig zijn voor droogstand.

De verdroging van groenvoorzieningen hangt met name samen met de afname van het bodemvochtgehalte in de wortelzone en het al dan niet toenemen van het zoutgehalte in de wortelzone. Naar verwachting zal het bodemvochtgehalte in extreem droge periodes sterk kunnen afnemen. Ook verzilting kan intenser worden. Er is echter weinig bekend over de gevolgen van droogte op stedelijke groenvoorzieningen door klimaatsverandering.

Kwetsbaarheid

Er is geen ruimtelijke informatie beschikbaar om heel precies de impact van droogte op groenvoorzieningen in beeld te brengen. Ook voor het visualiseren van de kwetsbaarheid van historische bebouwing in het stedelijke gebied is geen afdoende informatie beschikbaar. Wel kan de potentiële kwetsbaarheid worden aangegeven door alle

Figuur 7



Figuur 8

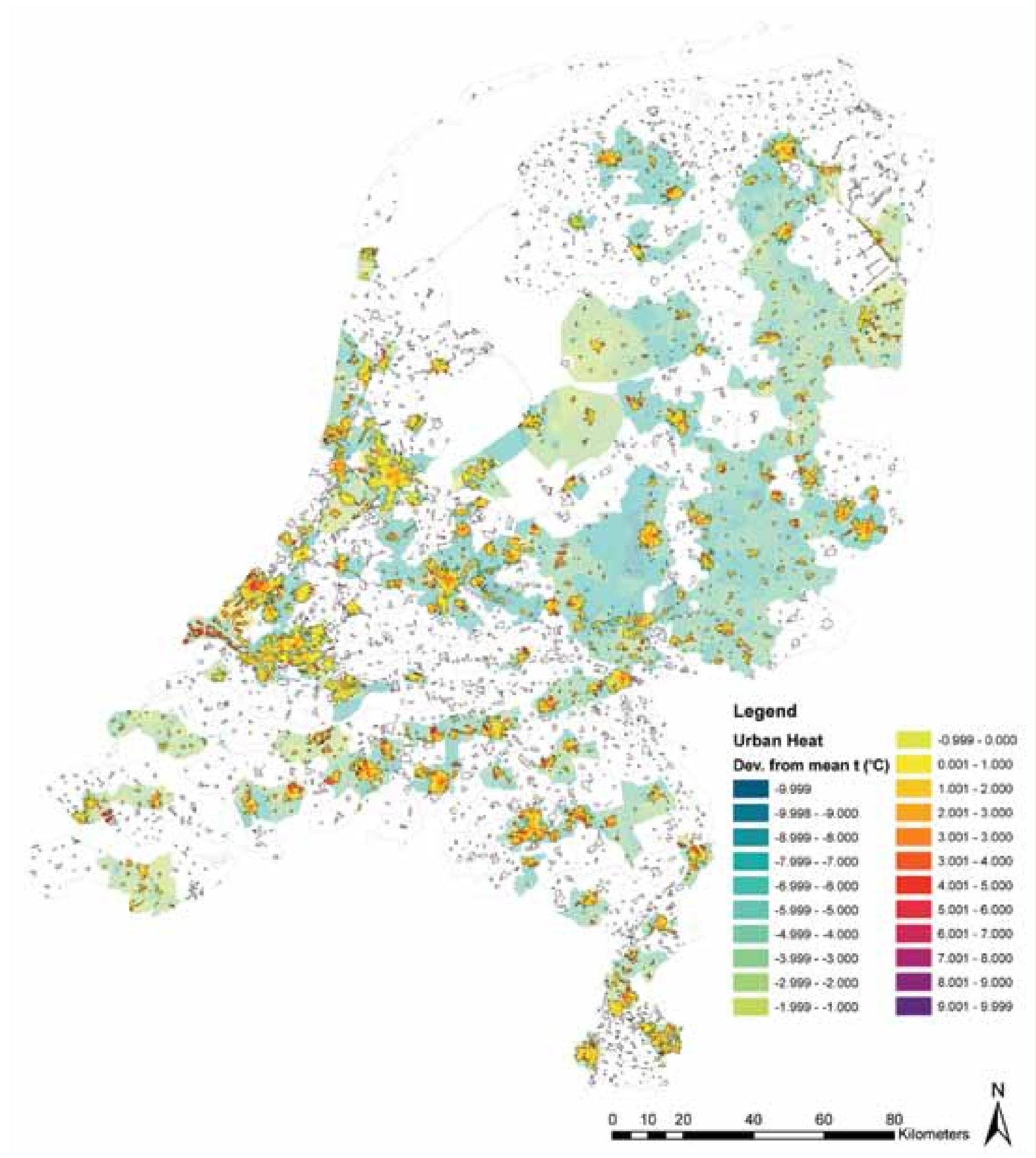
historische stadswijken in veen- en kleigebieden in vooral het noorden en westen van Nederland in beeld te brengen. Daaruit blijkt dat een derde van de historische gebouwen in Nederland kwetsbaar zijn voor droogte. In figuur 7 is een overzichtskaart opgenomen van historische wijken in klei- en veengebieden.

Veel bebouwing ondervindt nu al schade door droogte. Dit zal merkbaar gaan toenemen bij de verwachte klimaatsveranderingen, hoewel de exacte omvang niet goed te voorspellen is op dit moment. Droogteschade aan gebouwen, maar ook preventieve maatregelen, zorgen voor een aanzienlijke kostenpost voor huiseigenaren (herstelkosten van funderingen bedragen veelal meer dan € 40.000,-, ruwweg 10 tot 30% van de totale waarde van het pand). Veel historische panden zijn in particulier bezit.

2.5. Hittestress

Blootstelling

In steden is het warmer dat in het omringende landelijk gebied, ongeacht de ligging in Nederland.
Het stedelijk hitte eiland effect dat optreedt, wordt groter naarmate de gemiddelde temperatuur toeneemt. Ook neemt de temperatuur differentiatie binnen steden toe bij



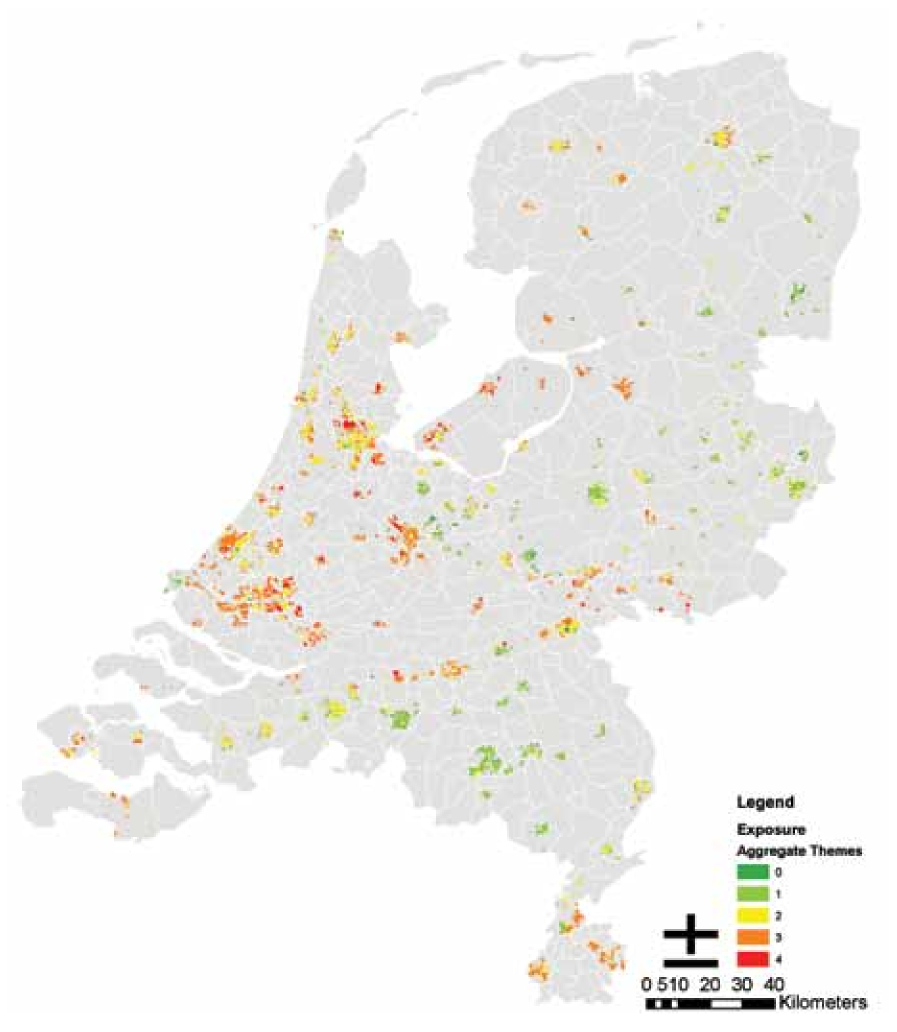
Figuur 9

hogere temperaturen. Dit resulteert in veel relatief warmere en koelere plekken binnen de stad. Echter, in bijna alle stedelijke typologieën vindt een verwarmend effect plaats. Figuur 8 laat zien dat bedrijventerreinen, industriële gebieden en hoogstedelijke centra de 'hotspots' zijn met de grootste blootstelling aan hittestress. De aanwezigheid van groen en water werkt verkoelend. Hierbij moet geconcludeerd worden dat parken meer verkoeling bieden dan enkele bomen in het straatbeeld.

Een landelijk beeld van de temperaturen is te vinden in onderstaand beeld; daarbij is uitgegaan van een gemiddelde temperatuur van 20 °C. Daaruit blijkt dat hittestress kan optreden in veel stedelijke kernen.

Gevoeligheid

Steden hebben in potentie een aanzienlijke schadegevoeligheid ten aanzien van hittestress. Zo kunnen er kwetsbare groepen mensen zoals ouderen aangewezen worden waarvoor grote gezondheidsrisico's aanwezig zijn. Deze kunnen door smog worden versterkt. Ook kan er een aanzienlijk verlies van arbeidsproductiviteit optreden en kunnen bepaalde gedeelten van de openbare ruimte onaangenaam of zelfs geheel ongeschikt worden voor gebruik zoals wandelen en winkelen. In combinatie met droogte kan schade aan openbaar groen en tuinen optreden. En ook asfaltwegen, rails en andere constructies kunnen door extreem hoge temperaturen forse schade oplopen. Echter, de schadegevoeligheid voor hitte is tot op heden zeer moeilijk te kwantificeren.



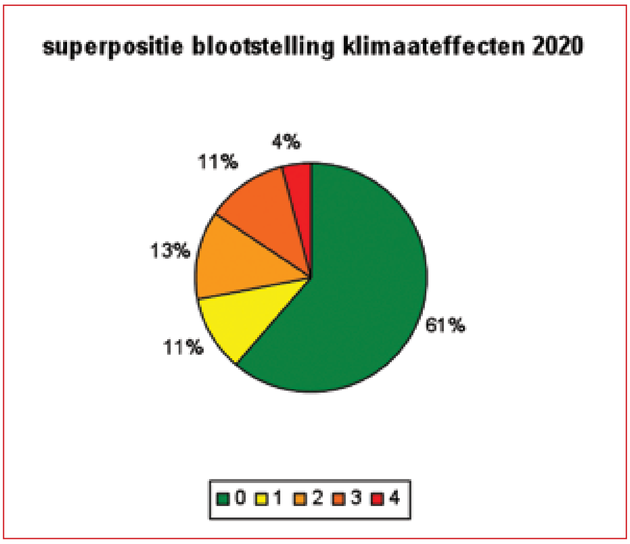
Figuur 10

2.6. Totaalbeeld

Door middel van *data mining* is de relatieve kwetsbaarheid voor overstroming, wateroverlast, droogte en hitte in kaart gebracht. Om inzicht te krijgen in de kwetsbaarheid van alle stedelijke gebieden zijn deze kaartbeelden samengevoegd volgens een *one out – all out* methodiek.

Het is niet mogelijk om aan te geven hoe zwaar de relatieve kwetsbaarheden tegenover elkaar gewogen moeten worden en bovendien maakt een falende bescherming op een van de klimaatthema's het betreffende gebied al kwetsbaar voor klimaatverandering. Deze samenvoeging levert voor alle stedelijke gebieden groter dan 30.000 inwoners het volgende beeld op van de huidige kwetsbaarheid. In de kaart staat aangegeven op hoeveel klimaatthema's het betreffende gebied kwetsbaar lijkt.

Zoals mocht worden verwacht zijn veel stedelijke gebieden nu wel op het ene of het andere punt kwetsbaar. Ook relatief 'jonge' steden als Almere en Lelystad zijn dus gevoelig voor klimaateffecten. Een relatie tussen de kwetsbaarheid en de stedelijke typologie ontbreekt.



Figuur 11

In alle onderzochte steden komen 'hotspots' voor, zeker voor de afzonderlijke klimaatthema's. Maar niet alle wijken en straten zijn als kwetsbaar aan te merken. Zelfs binnen wijken bestaat meestal een fors verschil tussen locale *hotspots* en minder kwetsbare gedeelten of straten.

Er is in algemene zin geen eenduidige relatie gevonden tussen de "stedelijke typologieën" zoals die worden onderscheiden door het PBL en de kwetsbaarheid ten aanzien van elk van de onderzochte klimaatthema's, met uitzondering van het thema hitte. Belangrijke kanttekening daarbij is de discrepantie tussen het detailniveau van enerzijds de kwetsbaarheid en de aanpasbaarheid met een resolutie van 25 x 25 m en anderzijds die van de stedelijke typologie met een resolutie van 250 x 250 m. Het gevolg van het combineren van beide gegevens is uitdemping van extreme waarden en dus verlies van informatie over de relatie tussen kwetsbaarheid en typologie.

Door de resolutie van onze basisinformatie – en gegeven het doel van deze studie – was een differentiatie van de kwetsbaarheid tot op het schaalniveau van individuele gebouwen niet mogelijk en onnodig. Maar toch zien we soms op het schaalniveau van 25 x 25 meter al belangrijke verschillen. Hotspots zijn vaak klein maar talrijk, zeker voor de afzonderlijke klimaateffecten.

Alleen voor de klimaatthema's overstromingsgevaar en wateroverlast zijn er regionale verschillen gevonden in de intrinsieke kwetsbaarheid van de bebouwde omgeving. Voor (grond)wateroverlast hangen deze samen met de geofysische eigenschappen van de ondergrond van het stedelijke gebied. In het laag gelegen West Nederland, waar ook voornamelijk een klei/veen ondergrond voorkomt, spelen deze drie thema's een rol van betekenis en hiervan is geen sprake bij zandgebieden (Oost Nederland).

Betrekken we bij dit beeld van de *kwetsbaarheid* ook de *aanpasbaarheid van het stedelijk gebied*, dan wordt inzicht verkregen in de potentiële toekomstige *kwetsbaarheid*. Indien alle gebieden die uiterlijk 2020 aan het eind komen van hun economische levensduur op een klimaatrobuuste wijze zouden worden heringericht, dan ontstaat het volgende beeld van de toekomstige kwetsbaarheid. De komende decennia kan bij bijna 40% van deze gebieden de kwetsbaarheid dan worden weggewerkt.

3. Adaptatie

De nadelige gevolgen van klimaatverandering kunnen in het stedelijk gebied worden ondervangen door tal van maatregelen. Alleen al voor het meer waterrobuust maken van een stedelijk gebied werd een lijst van meer dan 180 mogelijke maatregelen samengesteld. Van die maatregelen is een aanzienlijk deel zacht; denk aan de locatiekeuze voor stedelijke ontwikkelingen, bestemmingsplannen, bouwregels, rampen- en evacuatieplannen. Maar zeker de harde maatregelen zijn relevant voor de ruimtelijke ordening en de ruimtelijke inrichting. Die maatregelen kunnen collectief zijn, dus meerdere gebouwen beschermen, of individueel, dus per gebouw of bouwwerk worden gerealiseerd. Klimaatadaptatie is vaak maatwerk per gebouw!

Veel van de harde adaptatiemaatregelen zijn aan te merken als low-regret. Onder low-regret maatregelen worden hier verstaan maatregelen die vrijwel niets extra kosten indien ze worden genomen tijdens de aanleg of tijdens de herstructurering van gebouwen, straten en wijken.

De uiteindelijke keuze voor een bepaalde (combinatie van) maatregel(en) in een bepaald gebied of gebouw zal, conform de drietrapsbenadering voor waterrobuust bouwen, afhankelijk zijn van:

a. de uitkomsten van de kwetsbaarheidsanalyses;
b. een strategie die invulling geeft aan het versterken van het incasseringsvermogen, het herstelvermogen en het aanpassingsvermogen, in aanvulling op het vermogen om schade door extreme omstandigheden te voorkómen;
c. de lokale inpasbaarheid van en voorkeur voor bepaalde maatregelen, gegeven de specifieke situatie ter plaatse en de wensen van de betrokken partijen;
d. de vraag wie die maatregelen moet realiseren en wie verantwoordelijk is voor het beheer van de getroffen voorziening.

Deze afhankelijkheden en het zeer brede pallet aan mogelijke maatregelen hebben tot gevolg dat het op voorhand niet mogelijk is om “beste keuze(s)” te benoemen. Er zijn geen”one size fits all” maatregelen. De ter plaatse te realiseren maatregelen zullen het resultaat zijn van een gezamenlijk onderhandeling- en ontwerpproces met alle betrokken partijen. Klimaatbestendigheid is *tailor made*, mede omdat de kwetsbaarheid van plaats tot plaats sterk kan verschillen. Onderzoek naar gidsmodellen die dit keuzeproces kunnen ondersteunen is gaande, maar heeft nog geen bruikbare resultaten opgeleverd.

De keuze van adaptatiemaatregelen wordt nog complexer als we ons realiseren dat we bepaalde adaptatiemaatregelen vaak al in de eerste fase van de ruimtelijke planvorming, dus in de Rijksnota’s en in structuurvisies moeten opnemen, om die vervolgens uit te kunnen werken in bestemmingsplannen, vervolgens in stedenbouwkundige inrichtingsplannen en dan in de concrete bouwplannen. Die noodzaak van continuïteit maakt adaptatie tot een zaak van lange adem. Adaptatie kan alleen slagen als alle betrokken partijen er gedurende het gehele proces open over communiceren, daarover harde afspraken maken, die vastleggen in de verschillende plannen en overeenkomsten en elkaar vervolgens aan die afspraken houden.

Belangrijke instrumenten in dit adaptatieproces zijn dus de structuurvisie, het bestemmingsplan, het gebiedsontwikkelcontract tussen gemeente en projectontwikkelaars, het wateradvies, alsook de verschillende beheersplannen van gemeenten, waterschappen en woningcorporaties. Klimaatadaptatie kan in al deze documenten een vast onderdeel worden.

3.1. Aanpasbaarheid

Harde adaptatiemaatregelen worden getroffen op zowel het openbare als het private terrein, inclusief gebouwen en bouwwerken. Nieuwbouwgebieden kunnen dus relatief eenvoudig meer klimaatbestendig worden aangelegd en ingericht. Maar voor bestaand stedelijk gebied is de aanpasbaarheid veel beperkter. Eigenlijk kunnen adaptatiemaatregelen alleen tijdens grootschalige herinrichting goed en tegen beperkte kosten worden gerealiseerd. Pas dan is er een “*window of opportunity*”. In dit onderzoek is het adaptatievermogen daarom 1 op 1 gerelateerd aan de transformatiesnelheid van de attributen van de stad als gebouwen, wegen en openbaar groen. En die transformatie snelheid is afhankelijk van de ouderdom; oudere zaken

worden sneller op de schop genomen dan nieuwe. Globaal worden stedelijke gebieden iedere 50 jaar grondig heringericht.
Als we van die koppeling gebruik maken dan zou rond 2050 bijna 90 % van het stedelijk gebied aan vervanging toe zijn, gezien de ouderdom van de huidige vastgoedvoorraad. 37% van de bestaande gebouwde omgeving is op dit moment al economisch afgeschreven en zal derhalve binnen niet al te lange tijd – zeg de komende tien jaar - heringericht moeten worden. Zouden we alle te herstructureren stedelijk gebied daadwerkelijk gaan aanpakken en zouden we die gelegenheid gebruiken om deze gebieden dan klimaatbestendiger in te richten, dan zou een groot deel van de stedelijke gebieden de komende decennia kunnen worden aangepakt. Alleen de groeikernen van nu zijn dan laat toe aan het aanbrengen van adaptatiemaatregelen. In figuur 12 is aangegeven hoe zich dan het areaal ontwikkelt dat op een of meer klimaatthema's kwetsbaar blijft.

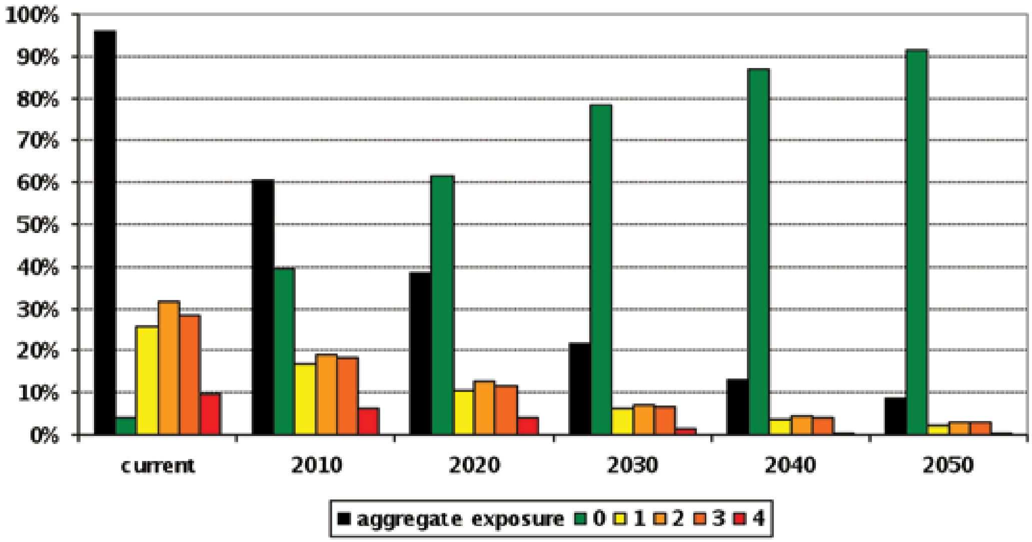
Uit dit beeld kan worden afgeleid dat de aanpasbaarheid van het stedelijk gebied aan klimaatverandering nu nog redelijk groot is. Maar stellen we het nemen van adaptatiemaatregelen uit dan missen we een belangrijke kans, omdat de komende 10 – 20 jaar een aanzienlijk deel van het stedelijk gebied dat is gebouwd in de periode 1950 – 1970 zullen moeten herstructureren. Het duurt dan naar verwachting weer zo'n 50 jaar voordat zich een nieuwe gelegenheid zal voordoen. Onzeker is of die tijd ons gegeven is, of dat we tegen hoge kosten "aanvullend" adaptatiemaatregelen moeten gaan treffen. Daarom is het aan te bevelen voortaan bij alle inrichtings- en herinrichtingsprojecten ten minste *low-regret* adaptatiemaatregelen te treffen. Deze maatregelen kosten vrijwel niets en leveren extra robuustheid tegen meer overstromingen en extreme weersomstandigheden.

3.2. Strategie

De potentiële aanpasbaarheid mag de komende 40 jaar dan groot zijn, dat betekent nog niet dat partijen tot aanpassing van hun inrichtingsplannen overgaan. Daartoe zullen door de verschillende overheden alle beschikbare instrumenten bewust en gericht ingezet moeten worden. Concreet noemen we hier:

- het beleid van de rijksoverheid op het gebied van waterbeheer, ruimtelijke ordening & inrichting, groen en nationale bouwregelgeving;
- het beleid van de provincies op het gebied van de ruimtelijke planning en het milieubeleid;
- het beleid van gemeenten zoals dat wordt vastgelegd in bestemmingsplannen, gebiedsontwikkelcontracten, milieuplannen en beheersplannen;
- het beleid van het waterschap zoals vastgelegd in de waterbeheersplannen en zoals dat wordt ondersteund door de watertoets en het wateradvies.

Particulieren en bedrijven zullen ontvankelijk moeten worden gemaakt om maatregelen op eigen terrein te treffen. Het is dan ook van belang dat de overheden alle priva-



Figuur 12

te partijen inclusief projectontwikkelaars, aannemers en burgers goed betrekken bij de planvorming, de uitvoering en het beheer van de adaptatiemaatregelen.

Overwogen kan worden om in de wet- en regelgeving rond locatie- en gebieds(her)ontwikkeling richtinggevende regels te gaan stellen, opdat verplicht aandacht wordt besteed aan de klimaatrobuustheid van plannen, net zoals er nu aandacht bestaat voor energiebesparing.

Maatregelen ter versterking van de klimaatrobuustheid zullen zelden spontaan worden genomen omdat voor veel burgers en private partijen de urgentie nog onvoldoende is aangetoond ("de koper vraagt er niet om") en omdat men bang is dat woningen en gebouwen er duurder door worden. Met bovengenoemde analyse is echter aangetoond dat (a) een groot aantal maatregelen kan worden beschouwd als (vrijwel) kosteloos en dus *low regret*, (b) dat niet overal tegelijk maatregelen getroffen hoeven te worden omdat de kwetsbaarheid voor klimaatverandering in bepaalde delen van het stedelijk gebied groter is dan in andere en (c) dat klimaatrobuustheid ook op de lange termijn gewaarborgd moet zijn, omdat het vastgoed en de inrichting pas na een zeer groot aantal jaren weer wordt geherstructureerd.

Deze houding kan worden doorbroken met wet- en regelgeving, maar ook kan worden ingezet op een communicatiespoor, via praktijkvoorbeelden, andere vormen van kennisverspreiding en het belonen van goed gedrag.

Ook lijkt het een veelbelovende strategie om adaptatiemaatregelen te verbinden met bredere maatschappelijke doelen zoals verbetering van de kwaliteit van de leefomgeving, met verduurzaming en met een inperking van de ecologische voetafdruk. Als voorbeeld noemen we benutting van het oppervlaktewater voor drijvende voorzieningen en/of voor laagwaardige watervoorziening. Het maatschappelijk draagvlak kan verder worden vergroot door maatregelen uit te werken tot een business case voor de private sector. Zij zullen invoering dan verder gaan ondersteunen.

3.3. Beleid

Diverse beleidsvelden zullen moeten samenwerken om de stedelijke omgeving meer klimaatrobuust te maken. Alle partijen die betrokken zijn bij de ruimtelijke inrichting kunnen daaraan bijdragen: ruimtelijke ordening, waterbeheer, rioleringbeheer, milieubeheer, volkshuisvesting, groenbeheer, industriebeleid, bouwregelgeving, financiële toezichthouders. Samen kunnen zij klimaatadaptatie mogelijk maken door vanaf vandaag low regret adaptatiemaatregelen te treffen daar waar de gelegenheid zich voordoet. Zo wordt voorkomen dat we over 20-30 jaar tegen hoge kosten corrigerend moeten ingrijpen in de stedelijke inrichting.

De keuze voor specifieke adaptatiemaatregelen moeten locaal worden gemaakt, omdat die sterk afhankelijk is van de locale omstandigheden en voorkeuren van de direct betrokken partijen. Hogere overheden zullen zich dan ook vooral moeten richten op het waarborgen van een zorgvuldig keuzeproces.

Tegelijk past het starten van een leertraject voor alle betrokken partijen, en wel op drie onderdelen:

- Het gedrag van het stedelijk systeem en al haar onderdelen tijdens blootstelling aan extreme klimatologische omstandigheden – inclusief overstromingen;
- De schadegevoeligheid van de verschillende onderdelen van het stedelijk systeem. Doel is om juist de kwetsbare objecten gericht te kunnen beschermen. Wellicht kan een verband worden gelegd met een typologie van wijken.
- De effectiviteit van adaptatiemaatregelen (werking, beheer en onderhoud), om vanuit de praktijk te leren wat het beste werkt. Daartoe moeten proefprojecten langjarig worden onderzocht, opdat de effectiviteit onder zeer extreme omstandigheden daadwerkelijk kan worden getest en geëvalueerd.
- Overwogen kan worden om voor dit doel van overheidswege een soort van Leergangen in te stellen die na afloop van kennisimpuls programma's als Klimaat voor Ruimte en Kennis voor Klimaat, een goede verspreiding van de kennis waarborgen.

4. Conclusies en aanbevelingen

4.1. Adaptatie

Aanbevolen wordt om voortaan niet al te dure adaptatiemaatregelen standaard op te nemen in (her)inrichtingsplannen van (potentieel) kwetsbare stedelijke gebieden en deze daadwerkelijk uit te voeren, ondanks de onzekerheid over de klimaatverandering en over de kwetsbaarheid van de stedelijke omgeving. Op die manier kan meer dan 80% van al het stedelijk gebied rond 2050 meer klimaatbestendig zijn ingericht. Veel van de adaptatiemaatregelen hebben ook positieve gevolgen voor de duurzaamheid en de kwaliteit van de leefomgeving, dus zijn ook om andere redenen aan te bevelen.
De keuze van adaptatiemaatregelen is sterk afhankelijk van de omstandigheden ter plaatse, alsook van de voorkeur van de actoren. Naast 'harde' inrichtingsmaatregelen kunnen tal van 'zachte' maatregelen worden getroffen om de kwetsbaarheid van het stedelijk gebied voor klimaatverandering te beperken. Alleen maatregelen die gevolgen hebben voor de ruimtelijke ordening en inrichting zijn in deze studie in beschouwing genomen. In aanvulling op adaptatiemaatregelen die erop gericht zijn om schade door extreme omstandigheden te voorkómen zullen ook maatregelen getroffen moeten worden om het incasseringsvermogen, het herstelvermogen en het aanpassingsvermogen van het stedelijk systeem te versterken.

Gezien de aard van de adaptatiemaatregelen kunnen deze eigenlijk alleen genomen worden tijdens de (her)inrichting van het gebied. Dan zijn veel van de mogelijke maatregelen aan te merken als *low-regret*, vanwege de lage kosten en de gunstige invloed op het risico. Maatregelen achteraf aanbrengen is meestal erg duur.

Ook al zijn een groot aantal adaptatiemaatregelen niet duur, dat wil nog niet zeggen dat publieke en private partijen ze nu spontaan zullen nemen. Daarom zal van overheidswege het beleid, de regelgeving en (het toezicht op) de uitvoering aangepast moeten worden. Klimaatadaptatie moet een vast onderdeel worden van het beleid inzake ruimtelijke ordening, waterbeheer, rioleringbeheer, milieubeheer, volkshuisvesting, groenbeheer, economische ontwikkeling, bouwregelgeving, en financiering. De bestaande wet- en regelgeving rond locatie(her)ontwikkeling, kan daartoe worden ingezet, inclusief de watertoets en de bouwregelgeving.

Over het algemeen geldt dat het introduceren van meer 'groen' en 'blauw' in de stad bijdraagt aan zowel het tegengaan van de gevolgen van (grond)wateroverlast als droogte en hitte stress.

De effectiviteit van veel adaptatiemaatregelen is nog moeilijk te kwantificeren. Vandaar de aanbeveling om vooral low-regret aatregelen toe te passen. Daarenboven zullen we de komende jaren een op de praktijk gericht gezamenlijk leertraject op moeten zetten om beter zicht te krijgen op het gedrag van het hele stedelijke systeem bij extreme blootstelling en op de effectiviteit van adaptatiemaatregelen onder die omstandigheden.

4.2. Kwetsbaarheid

Het stedelijk systeem is kwetsbaar voor de gevolgen van klimaatverandering, dus voor meer extreme overstromingen, voor meer wateroverlast, langdurigere perioden van droogte en meer extreme hitte. Deze studie werpt weliswaar licht op de *relatieve* kwetsbaarheid van straten en wijken, maar een uitspraak over de absolute kwetsbaarheid is niet haalbaar gebleken. De kwetsbaarheden voor overstroming, wateroverlast, droogte en hitte kunnen niet bij elkaar worden opgeteld; eerder past een *one out – all out* benadering van de kwetsbaarheid, omdat de leefomgeving robuust moet zijn op al die klimaatthema's.

De kwetsbaarheid van het stedelijk gebied is niet enkel een gevolg van een meer frequente en meer extreme blootstelling aan extreme weersomstandigheden maar ook van de schadegevoeligheid van het stedelijk systeem. Adaptatiemaatregelen zijn daarom deels gericht op het beperken van de schadegevoeligheid.
Voor verschillende onderdelen van het stedelijk systeem is die schadegevoeligheid nog niet goed in kaart gebracht. Als voorbeeld noemen we wegen, de netwerken voor elek-

triciteit, telecommunicatie, gas en water, specifiek kwetsbare objecten zoals ziekenhuizen, gebouwen van hulpdiensten, rampenzenders, enzovoorts. Ook de effecten van extreme weersomstandigheden op de volksgezondheid en de gezondheid van het stedelijk ecosysteem zijn vrijwel onbekend.

Gebleken is dat door middel van *data mining* een eerste inschatting is te maken van de relatieve kwetsbaarheid van straten en wijken voor overstromingen, wateroverlast, droogte en hitte. De mate van blootstelling bleek tot op zekere hoogte af te leiden uit alle beschikbare informatie. Echter, over de kans op een bepaalde blootstelling en over de schadegevoeligheid bleek niet of nauwelijks informatie af te leiden. De kwetsbaarheid van een gebied was (nog) niet te koppelen aan de typologie van het stedelijk gebied zoals die door het PBL wordt gehanteerd. Meer studie is nodig naar de kans op blootstelling en naar de schadegevoeligheid van het stedelijk systeem om wellicht een koppeling te kunnen leggen.

Om de kans op schade door wateroverlast, overstroming, droogte en hitte te beperken, is het aan te bevelen om een actief beleid te voeren danwel regels te stellen inzake een waterrobuuste inrichting van woningen, tuinen en straten. Als gevolg van de klimaatverandering zal zonder maatregelen de grondwateroverlast in vrijwel alle stedelijke gebieden toenemen. Daar staat tegenover dat door droogte op diverse plaatsen de houten palen onder oude woningen en gebouwen – ons cultureel erfgoed – door aantasting zal worden bedreigd. De aanpak van dit onderlastprobleem is complex, duur en urgent. Extreme droogte kan ook leiden tot problemen met de fundering van gebouwen door versterkte zetting en inklinking van de bodem. Zetting en inklinking leveren ook forse schade op aan bestrating, kabels en leidingen. Maar omdat de schadegevoeligheid niet bekend is kan deze niet worden gekwantificeerd.

Het stedelijk groen lijkt weinig gevoelig voor meer extreme droogte, maar de waterbehoefte voor het op peil houden van het oppervlaktewater en het grondwater en voor de watervoorziening van groene daken en tuinen zal toenemen.
De toenemende hittestress kan leiden tot een toename van het gebruik van airconditioning, tenzij we in staat zijn die extreme hitte op een andere wijze weg te nemen. Water speelt daarbij een essentiële rol als koelvloeistof van de stad. Door de verdamping te bevorderen wordt de temperatuur van de lucht verlaagd. Aanbevolen wordt om na te gaan hoe deze techniek kan worden ontwikkeld om het energieverbruik van traditionele airconditioning niet verder te laten toenemen.
De hittestress binnenshuis en buiten zijn sterk afhankelijk van de inrichting van de stedelijke omgeving, dus zijn er mogelijkheden bij nieuwbouw en herstructurering om de leefomgeving minder gevoelig te maken voor hittestress door een slimme vormgeving en inrichting.

1. Introduction

1.1. Background and scope

An advanced understanding of the potential negative long-term consequences of climate change on urban areas calls for a proactive and adaptive policy. It is imperative to develop suitable coping strategies and measures that will lead to a better spatial design of urban areas and tackle negative influences on the city's climate and urban functions (buildings, installations, infrastructure, parks, water systems, etc.). The climate change effects on cities should therefore be determined. This way, we can choose adequate adaptation options for urban surroundings in The Netherlands and, subsequently, assure the quality of life in these urban areas. The implementation of possible adaptation options will, in most cases, go hand-in-hand with planned redevelopment and restructuring of urban areas. It will therefore take decades before all urban areas will be equipped against the effects of climate change. This underlines the necessity for a consistent long-term policy even more.

Over the past years, extensive attention has been given to climate change, its consequences and the possible measures to limit these consequences. National and international research programmes have resulted in broad and diverse methods, literature descriptions and recommendations. Many of the conducted research have focused on a specific climatologic topic (e.g. temperature change), effects (e.g. increased risk of flooding) or a small number of case studies. It is therefore unclear if these study results can be applied on a wider scale. This limits the possibilities to frame the consequences of climate change for regional and national policy. A more holistic appraisal of vulnerability of urban areas is necessary, including the possibilities for adaptation.

Climate Change will not only cause a change in expected weather patterns trends, but also in a larger variability (e.g. more extreme rainfall events and periods of drought). New insights reveal the necessity to incorporate the effects and consequences of climate change into spatial planning. Although climate change predictions still contain great uncertainty, it is expected that new requirements will be set to the robustness and adaptation strategy for the built environment.

1.2. Research questions and objectives

In this report an assessment framework for the vulnerability of urban areas is presented. Furthermore, this report provides building stones for national policy directed towards climate robust urban areas. The following research questions are central in this report:

1. Where (what physical system) does climate change have an effect on urban areas?
2. How can society cope with these effects, so what adaptation options are there?
3. What are the merits and consequences of these adaptation options?

The aim of this study is to roughly determine the technical, social and economic consequences of adaptation to climate change in urban areas. The national government can use the outcome to define a national policy framework for creating climate robust urban areas in The Netherlands.

1.3. Approach

Not only the climate and subsequent effects will change in the coming decades. Urban areas will also undergo many changes and cycles of renewal and expansion. To investigate the vulnerability of urban areas to climate change and determine adaptation strategies, one should consider not only the physical effects of climate change but also urban developments and social and economic changes. Figure 1.1 provides the reader an overview of the actual components that determine current and future urban vulnerabilities to climate impacts.

Chapter 2 describes the expected trends that act as the main drivers that determine the future vulnerability of urban areas to the climate change consequences. The overall methodology and relevant definitions are further described in Chapter 3.

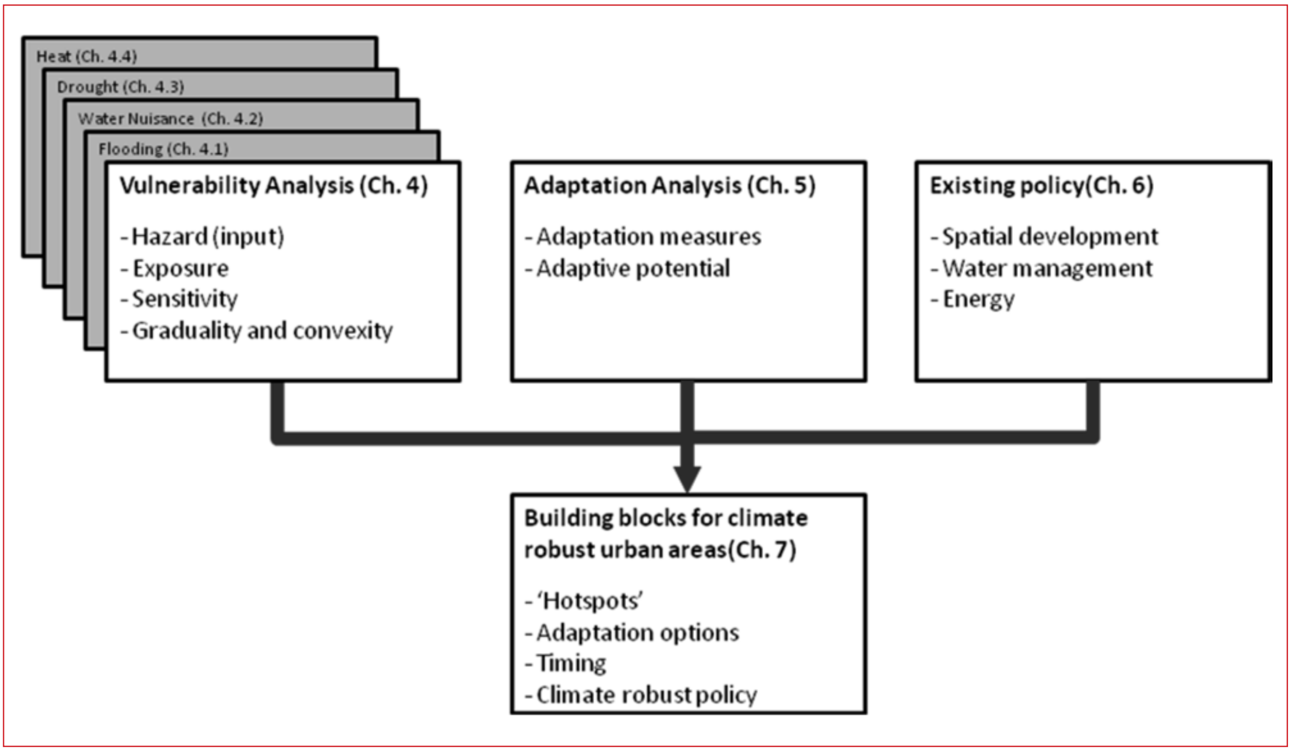


Figure 1.1 General approach of this study

In this study, the consequences of climate change on urban areas are determined by assessing the 'intrinsic vulnerability' of the following themes:

- water safety (flooding);
- water nuisance (pluvial flooding and high groundwater levels);
- drought (water shortage); and
- heat stress (urban heat island effect).

The intrincis vulnerability is defined as the product of the climate effect (hazard), the exposure of urban areas to the climate effect and the sensitivity of urban functions and urban inhabitants (possible damage). It should however be noted that the sensitivity has proven to be very difficult to asses. Chapter 4 highlights the intrinsic vulnerability of urban areas in The Netherlands for the four different themes.

The concept of vulnerability is defined as the combination of intrinsic vulnerability and adaptive capacity. Areas are considered vulnerable when they are exposed to climate hazards and the adaptive capacity is low.

The next step is therefore to determine the adaptive capacity and the best adaptation measures to enhance the robustness of urban areas based on the four different themes that determine the intrinsic vulnerability. Restructuring of existing urban areas that have reached the end of their life cycle provides an opportunity to implement adaptation options at relatively low costs. Chapter 5 will focus on issues concerning the adaptive capacity which provides a window-of-opportunity for the reduction of current and future climate impacts. In this chapter we describe the possibilities to couple adaptation with urban renewal and how to quantify the number of urban areas that can be made climate robust in the coming decades. Chapter 5 highlights the benefits as well as the financial consequences of climate change adaptation.

The lessons learnt from existing urban areas provide a basis for climate robust development of new urban areas. In combination with existing policy instruments for spatial development, water management and energy, these lessons provide the necessary knowledge for the formation of building blocks for adaptive policies within urban (re) development. These are described in chapter 6. The translation into long-term policy recommendations has been incorporated in the conclusive Chapter 7.

1.4. Project team and experts

This study has been conducted in the framework of the 'Knowledge for Climate' research project. The main focus of this particular study is the urban areas of The Netherlands. Together with investigations into rural areas and areas alongside the large rivers, this study forms the preliminary study for Building The Netherlands Climate Proof.

The study has been conducted by a consortium of IHE-Unesco and Deltares. The Netherlands Environmental Assessment Agency (PBL) supervised the project and ensured a link to other national research investigations on climate change. Also, Jitze Kopinga of Alterra has contributed by sharing his knowledge on the effects of climate change on city parks.

2. Trends in Dutch Urban Areas

To better understand how, where and when climate change will affect Dutch urban areas and to identify adequate adaptations, it is important to determine the most important trends for the coming decades. These trends are:

- Climate change effects and consequences;
- Expected urban trends (urban sprawl, urban renewal and urban shrinkage);
- Presumable social-economic growth scenario.

This chapter gives a general outline of these trends.

2.1. Climate change

Climate change is one of the major environmental issues for the coming years, both regionally and globally. The Netherlands is expected to face climate change impacts on all land use related sectors and on water management, and therefore on spatial planning in general. On 30 May 2006, the Royal Netherlands Meteorological Institute (KNMI) presented four climate scenarios for The Netherlands. These so-called KNMI'06 scenarios currently serve as the national standard for adaptation strategies.

The scenarios differ in the degree of global temperature rise and the degree of change in atmospheric circulation patterns above The Netherlands (Figure 2.1). The W/W+ scenarios are characterised by a strong increase in the global mean temperature, whereas this increase is moderate in the G/G+ scenarios. In the G+/W+ scenarios, a change in the atmospheric circulation above the Atlantic Ocean and Western Europe leads to extra warm and wet winters, whereas the summers are extra warm and dry. In the G/W scenarios, the influence of circulation changes is small (KNMI, 2009).

In The Netherlands, climate change will affect temperatures, sea levels, river discharges and groundwater levels. This will have an impact on urban functions, especially in lower lying areas along side the large rivers and close to the sea. The consequences of climate change and the vulnerability of urban areas are further described in Chapter 4.

2.2. Socio-economic growth scenarios

The societal response to the consequences of climate change (e.g. implementation of adaptation measures) will largely depend on social and economic developments in the coming decades. Centraal Planbureau (CPB) has outlined four different economic growth scenarios for Europe and The Netherlands in particular (CPB, 2004). Figure 2.2 summarizes these four scenarios.

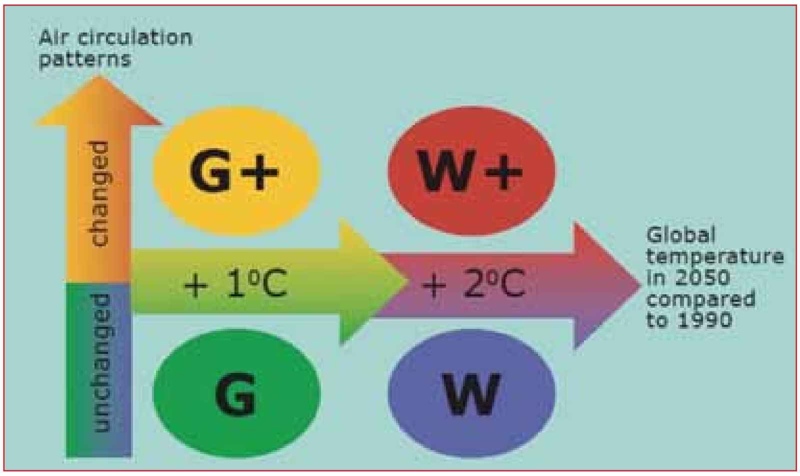
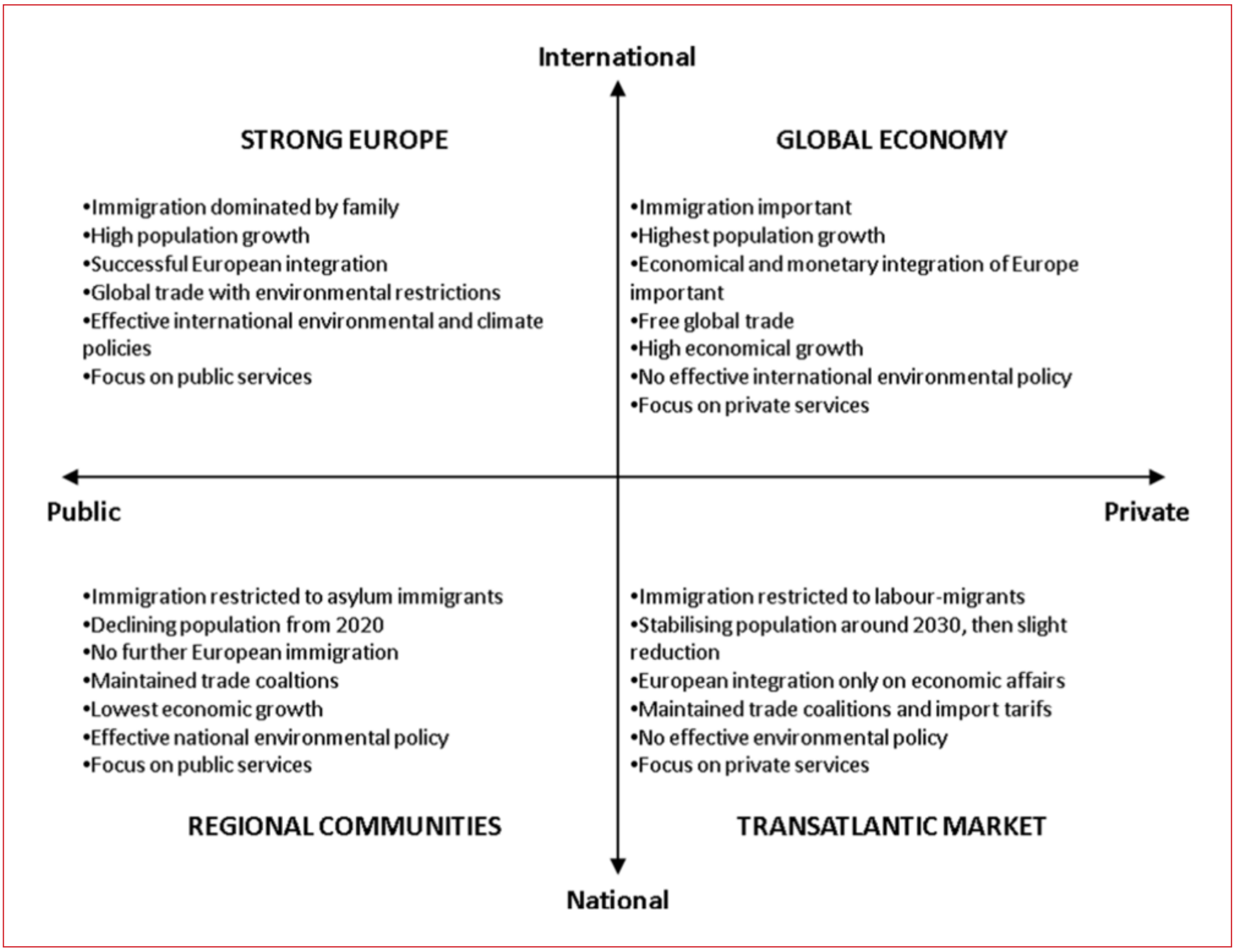


Figure 2.1 Classification of the four KNMI'06 climate scenarios



STRONG EUROPE

- Immigration dominated by family
- High population growth
- Successful European integration
- Global trade with environmental restrictions
- Effective international environmental and climate policies
- Focus on public services

GLOBAL ECONOMY

- Immigration important
- Highest population growth
- Economical and monetary integration of Europe important
- Free global trade
- High economical growth
- No effective international environmental policy
- Focus on private services

REGIONAL COMMUNITIES

- Immigration restricted to asylum immigrants
- Declining population from 2020
- No further European immigration
- Maintained trade coaltions
- Lowest economic growth
- Effective national environmental policy
- Focus on public services

TRANSATLANTIC MARKET

- Immigration restricted to labour-migrants
- Stabilising population around 2030, then slight reduction
- European integration only on economic affairs
- Maintained trade coalitions and import tarifs
- No effective environmental policy
- Focus on private services

Figure 2.2 Socio-economic growth scenarios (CPB, 2004)

In the Strong Europe and Global Economy growth scenarios, high economic growth and high population growth will result in an increased sensitivity of cities to climate effects. This is caused by increased potential damage and population density. To a lesser extend, this holds also true for the Regional Communities and Transatlantic Market growth scenarios.

From the Transatlantic Market and Global Economy growth scenarios it can be expected that climate adaptation will, to a large extend, only be considered in concurrence with plan development, existing maintenance programmes or to comply with regulations (‘no regret’ measures).
In contrast to the Strong Europe and regional Communities growth scenarios, additional measures are not likely to be taken by the national government for the Transatlantic Market and Global Economy growth scenarios.

2.3. Urban sprawl and urban shrinkage

Over the last decade, urbanization has drawn much global attention of scientists, policy makers and urban planners. In 2008, 50% of the worlds’ population lived in cities. This number is expected to grow even further in the future. The surface area of cities has also grown exponentially after World War Two, causing an unprecedented urban sprawl. Also in The Netherlands, a large part of the population lives in cities. The urban population and household numbers, however, are stabilizing and even declining on the long term (see Figure 2.3).

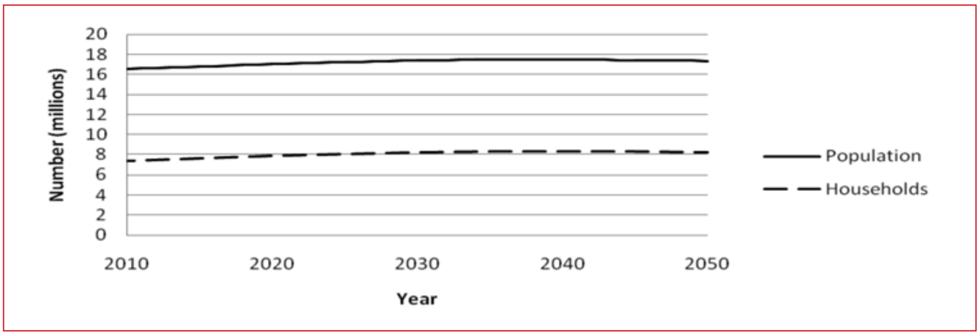


Figure 2.3 Prediction of growth of population and households in The Netherlands (Data: CBS)

Currently, population decline is already taking place in several parts of The Netherlands (see Figure 2.3). In 2006, van Dam et al. (2006) and Derks et al. (2006) almost simultaneously published a report on this phenomenon, which set the topic on the national policy agenda. Since 1997, there has been negative population growth in Limburg (Smeets et al., 2008). South Limburg and East Groningen are facing the largest population decline, but other regions such as Zeeland, Drenthe and the central part of The Netherlands are expected to follow shortly (Raad voor het openbaar bestuur and Raad voor de financiële verhoudingen, 2008). CBS has prognosed that 56% of all municipalities will be facing population decline over the next 20 years (REF). Furthermore, in 20% of the municipalities the number of households will also decline. Locally, the trend may not be as gradual as the national trend. When the baby-boom generation (1945-1965) dies, a steep decline of the population is expected (Smeets et al., 2008). For municipalities with a large population in this category, an accelerating population decline is expected between 2025 and 2045.

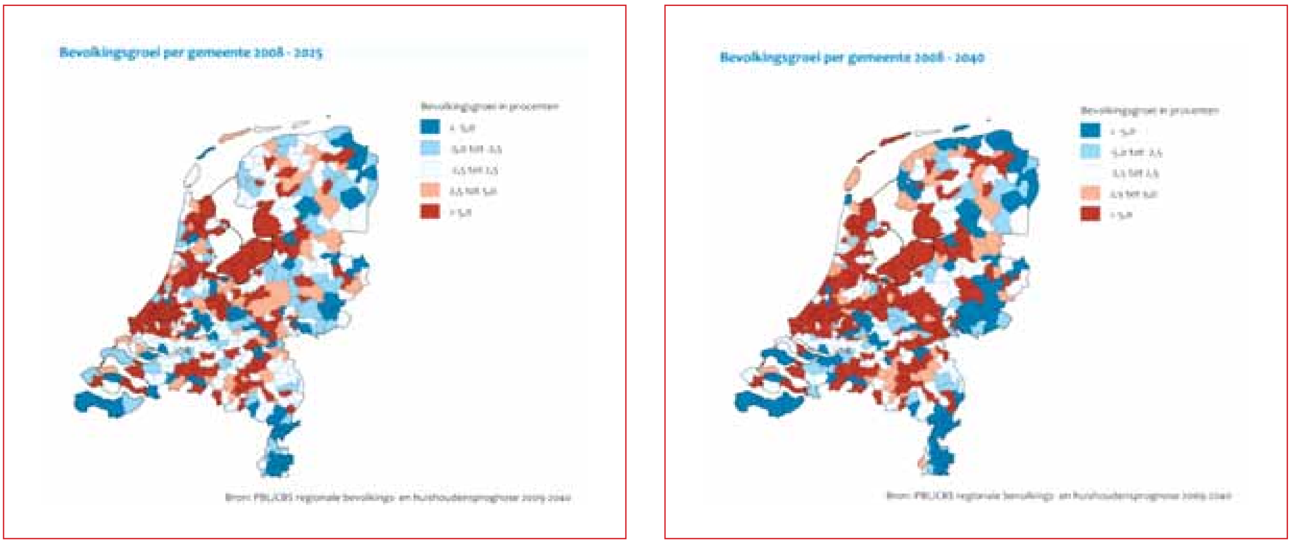


Figure 2.4 Population growth per municipality (%) in 2008-2025 (left) and 2008-2040 (right)

3. Methodology

3.1. General approach

The aim of this study is to provide building blocks for climate change adaptation in urban areas in The Netherlands. This is established by integrating the existing state-of-the-art into a framework in which different topics, components and outcomes are brought together. For the sub-topics, the study relies on existing knowledge and proven methodologies. Apart from an extensive literature review, out-of-the-pocket knowledge has been acquired by interviewing experts.

Urban adaptation as a response to climate change operates within a framework consisting of many components. While various frameworks exist to explain the relation between different components (e.g. the source-pathway-receptor model) standards for a comprehensive framework including adaptation do not exist. For the urban condition, the components and relations are summarized in figure 3.1. The components consist of:

- *Climate change*. The main global driver of changing weather patterns;
- *Hazard*. Specific climate related events (e.g. precipitation event, storms, heat waves);
- *Exposure*. The extent and intensity where the hazard comes into contact with assets (built environment, people, ecosystems, etc.);
- *Sensitivity*. The level in which exposure to some climate related effect (e.g. flooding) results in an effect (e.g. damages, health problems);
- *(Intrinsic) vulnerability*. The aggregation of exposure and sensitivity;
- *Climate governance*. The policy framework in which climate related problems is addressed by formulation of incentives, guidelines and measures;
- *Adaptation measures*. Actual responses to mitigate the impacts of climate related effects. Note that these can be structural and non-structural;
- *Adaptive capacity*. The ability to apply climate related responses. Note that the adaptive capacity does not necessarily relate only to the current response capacity but also includes the capacity for future responses;
- *Autonomous development*. Societal changes not necessarily related to climate change which to some extend influence the socio-economic conditions for adaptation response as well as the development of the urban environment;
- *Urban development*. The combination of autonomous urban development and ‘climate change-aware’ development resulting in different levels of exposure and sensitivity towards climate related effects.

Climate change has a direct effect on a hazard level but the actual impact on the urban area is felt through the structural and non-structural components that make up our cities. These components define to a large extent the exposure, sensitivity and ultimately the vulnerability and adaptive capacity of our urban areas. Within this framework it is vital to understand that urban development can increase the exposure and sensitivity towards the impact of natural hazards (e.g. Pielke et al, 2007). For example, building in low-lying polders, urban densification and aging infrastructure increases a city’s vulnerability to climate hazards, even without climate change taking place.

While vulnerability assessment and determination of adaptive capacity are two relatively independent components, they are integrated into a single framework, because reviewing adaptation measures can only be performed by application of detailed knowledge about the vulnerability aspects. This determines to a large extent the necessity, applicability and urgency for adaptation measures at a given location by specifying potential current and future climate impacts.

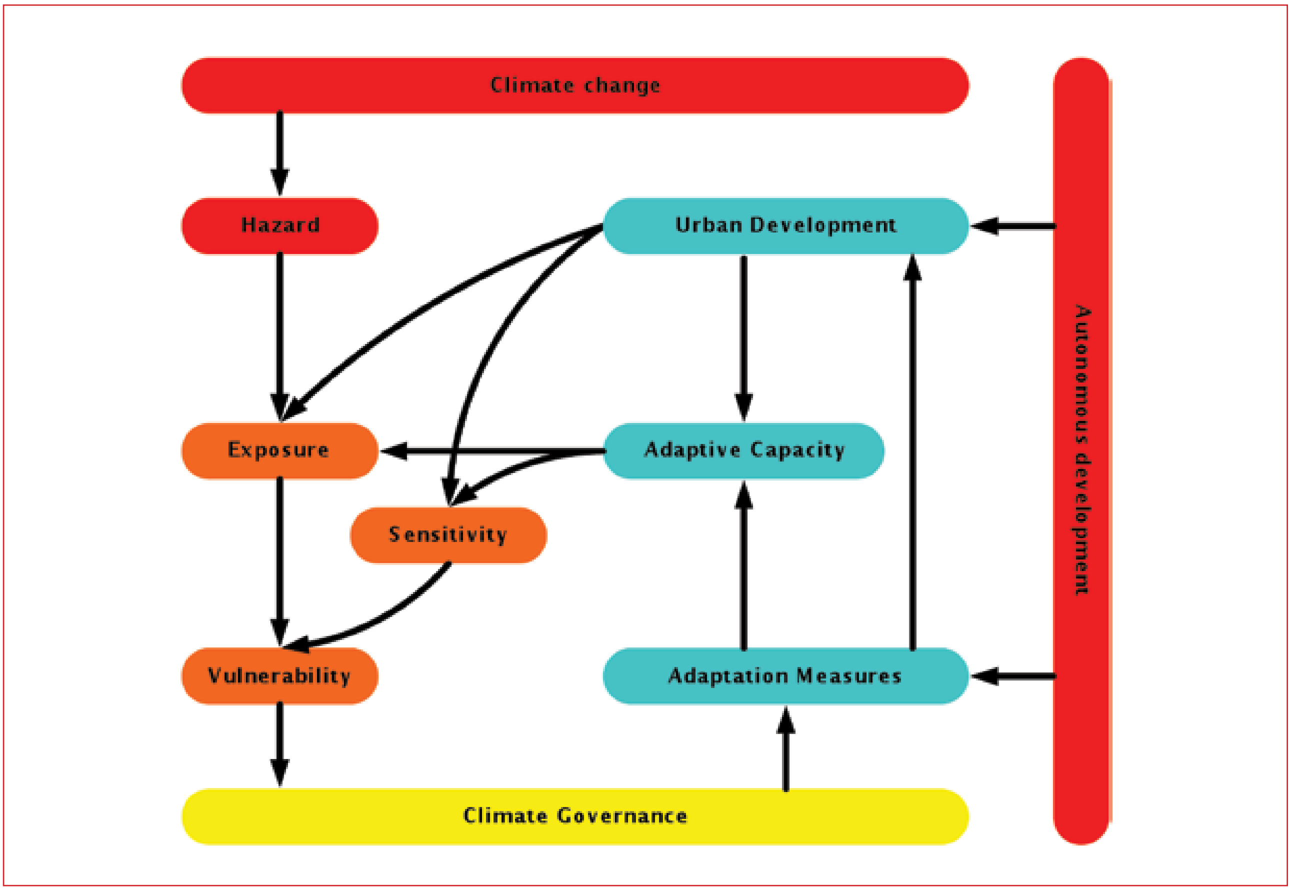


Figure 3.1 Schematic overview of climate adaptation

Conversion of many of the components depicted in Figure 3.1 into operational, expressive and usable models is by no means trivial, especially when they are assessed quantitatively. Operational definitions of the concepts are often surrounded by constrains and uncertainties. In addition, they are subject to continuous revisions. It is therefore vital to discuss some of these issues since they define to a large extent the applicability and reliability of the results.

- *Stressor levels and norms.* Risk and vulnerability mapping often focuses on the implications of a chosen event which is associated to some norm (e.g. a 100 year flood). Nevertheless, within the context of climate change it is important to focus on a range of events. Currently, consensus exists that climate should be regarded as a dynamic system (Milly et al, 2008). Application of 'standard' events is therefore no longer a feasible strategy to obtain insights into expected natural hazard impacts and responses.
- *Climate change, hazards and probabilities.* Over the last years, a substantial body of scientific evidence has been presented supporting the claim that climate change increases uncertainty levels in the statistical distribution of flood probabilities (e.g. Kabat et al, 2005; EEA, 2006). Therefore it seems unproductive to focus exclusively on exceedance probabilities since climate scenarios are updated frequently. The resulting probability distributions differ and former assessment require adjustment. An alternative approach is to focus on stressor levels, i.e. the intensity of some climate related event (e.g. precipitation).
- *Extreme events.* The notion of the occurrence of 'extreme events' is highly uncertain. Methodologies concerning extreme value estimation, in which observed events with moderate return periods are extrapolated to extremely long return periods (e.g. 10,000) are error prone (e.g. Makkonen, 2008). Thus, the confidence interval for extreme events is much smaller which subsequently might lead to overestimation of return periods.
- *Graduality*. The distribution of expected impacts might not be proportional to increasing return periods or stressor levels. A small increase in temperature might for instance lead to disproportional heat stress levels. Insight into this distribution is vital for risk evaluation.

Applicable metrics to express the smoothness of impact levels over a range of stressor levels is found in the concept of graduality (Bruijn, 2005).

- *Exposure and level of detail*. Natural hazard impact assessment is often performed on case-study level or in comprehensive comparative studies. Studies on case-study level often focus on a single topic which is covered in-depth. This requires application of data intensive, complex models which result in highly detailed outcomes. Integrated comparative studies on regional or national level on the other hand, often use broad sets of indicators and strong schematization in which local features are generalized.
- *Sensitivity*. Climate impact assessment covers a broad spectrum of tangible (e.g. costs resulting from structural collapse, cleaning costs) and intangible (e.g. health risks, loss of life, cultural value of objects) damages. This multi-modality makes a comparative assessment difficult if not impossible. Furthermore, methodologies for direct damage assessment are still under development. Although somewhat standardized for the topic of water safety, they are still highly volatile and error prone (e.g. Veerbeek and Zevenbergen, 2009).
- *Vulnerability*. Generally, vulnerability is expressed as a function of hazard, exposure and sensitivity (e.g. ISDR, 2004; Turner II et al, 2003). It is therefore a ‘container’-concepts in which errors, assumptions and uncertainties regarding hazard, exposure and sensitivity are amplified and become intractable.
- *Adaptive Capacity*. The adaptive capacity towards current and future natural hazard impact is a function of a broad range of structural and non-structural responses. All these response modalities operate within a spatial and temporal dimension in which their effects need to be evaluated. Up till now, comprehensive frameworks in which all modalities are integrated and evaluated hardly exist; the cumulative effects of (combinations) of responses can only be measured using many constrains and assumptions. Therefore, the adaptive capacity usually is expressed within a relatively narrow scope (e.g. the potential to increase the storm water drainage capacity to withstand increasing precipitation levels). Note that some researchers (e.g. De Graaf, 2008) consider the adaptive capacity only in relation to the potential to keep up with slow trend changes resulting from climate change.
- *Autonomous development*. The uncertainties about climate change are small when compared to those resulting from autonomous development (compare the ranges within current climate scenarios to those for development scenarios, e.g. DTI, 2002). Future economic, social and cultural changes will have significant impacts on our (physical) environment. Similar to climate change assessment, these changes are described using scenarios. Although speculative (many factors within these scenarios are highly volatile), they do provide insights into possible futures. One of the main problems in application of these scenarios is that they are highly narrative and abstract. Within detailed studies where for instance the location and size of the urban extent plays a crucial part in the susceptibility towards natural hazards, off-the-shelf models do not exist. Spatial and subsequent quantitative analysis in which autonomous development is taken into account is therefore hard to find.
- *Mitigation*. The resulting effects of climate mitigation (and their predicted application in the future) are highly volatile and uncertain. Although they often are included in comprehensive frameworks, operational models are up till now only provided on global scale (e.g. Stern).
- *Climate and Urban Governance*. As for some of the other factors, insights into the future effects of governance are highly speculative. Especially since they involve behavioural components, the uncertainties are immense. Nevertheless, they provide a practical framework for implementation of urgent actions in which not so much the effects of policies are assessed but the changes required to adopt measures into a consistent batch of incentives, policy and regulations.

While many of these issues are related to knowledge gaps, fundamental uncertainties or issues related to complexity, there are also a large amount of practical issues that need to be taken into account when aiming for integrated climate adaptation assessment. These include issues concerning:

- *Data requirements*. Although detailed data is increasingly available, there are still fundamental gaps when aiming for detailed studies covering large areas. Often, data available from one city or municipality is not available for another. This could either be compensated by making assumptions about sparsely covered areas based on outcomes for areas in which the necessary data is available, or by simply limiting the scope on data available for all areas. The first method might lead to false claims caused by generalization of outcomes, while the second might lead to over-schematization within models resulting in limited applicability of outcomes.

- *Model complexity*. Since no off-the- shelf products for integrated vulnerability and climate adaptation assessment exist, many of the methods used might not be sufficiently validated and verified to generate reliable outcomes. This applies mostly to areas where individual models interface and produce aggregate results. Especially since integrated assessment consists of many interacting components, a broad range of variables, schematizations and ultimately assumptions need to be considered. While sensitivity analyses are often applied on component level, a thorough analysis of the complete model is often absent.
- *Computational load*. Although computation power is increasing rapidly, many of the calculations involved are not performed on the highest level of detail. The required computational time would simply become unfeasible for the limited period most projects are planned in. Grid-computing might provide the answer to this limitation but is still not integrated in most model platforms.

All in all, many of the described issues seem to limit the scope, precision and application of the outcomes in relation to the aim of this study. Nevertheless, this doesn't mean that this task is futile; it merely puts the outcomes in perspective and defines constrains for the task of translating some of the concepts into operational models.

3.2. Conceptualization of vulnerability

Within this study, the conceptualization of vulnerability relies on the range of climate hazards, the resulting exposure and the possibilities for adaptation. The climate hazards are expressed as a range of stressor levels (e.g. ambient temperature for heat stress determination). After application of the associated models (e.g. runoff calculation in combination with local sink evaluation) the outcomes define the resulting exposure. A qualitative assessment is provided for the sensitivity of the urban areas. These are combined into the 'intrinsic vulnerability' in which exposure and sensitivity are combined with the actual local conditions on a high level of detail.

The adaptive capacity is determined by evaluating the lifespan of the buildings stock on district and neighbourhood level as well as for a range of urban typologies (e.g. industrial areas, peripheral housing areas). When the end of the lifespan is reached, 'climate proofing' measures can be taken either through active retrofitting during redevelopment or within the replacement of buildings. Finally, the concept of vulnerability is defined as the combination of intrinsic vulnerability and adaptive capacity. Areas are considered vulnerable when they are exposed to climate hazards and the adaptive capacity is low, i.e. the area did not reach the end of its lifespan. The acquired vulnerability therefore includes a temporal dimension; the vulnerability is always related to some period in time and thus differs over time. The conceptualization of vulnerability is described in Figure 3.2.

One of the main assumptions in this project is that in order to generate accurate results within urban regions, the existing high level of differentiation within and between cities should be acknowledged. Instead of using base figures or estimated neighbourhood averages. The study was performed on a relatively high level of detail making ot possible to take into account the interaction between stressors (e.g. rain, heat) and individual buildings, streets and other urban features. This also is in agreement with the notion that Dutch cities show substantial typological differences. Contrary to e.g. American suburbs or Eastern European cities, Dutch cities show many different characteristics ranging from historical centres along canals to sparsely populated garden cities.

Nevertheless, it is unfeasible to reach any conclusions (let alone policy recommendations) without some level of spatial generalization. Spatial generalization is also required to be able to perform comparative studies and identification of correlation between urban features and climate impact levels. Insight in the methods used to calculate both aggregate and average results are provided per theme in Appendix A.

The following paragraphs give more insight into the methodologies and definitions which were applied for the evaluation of the different aspects pictured in Figure 3.2.

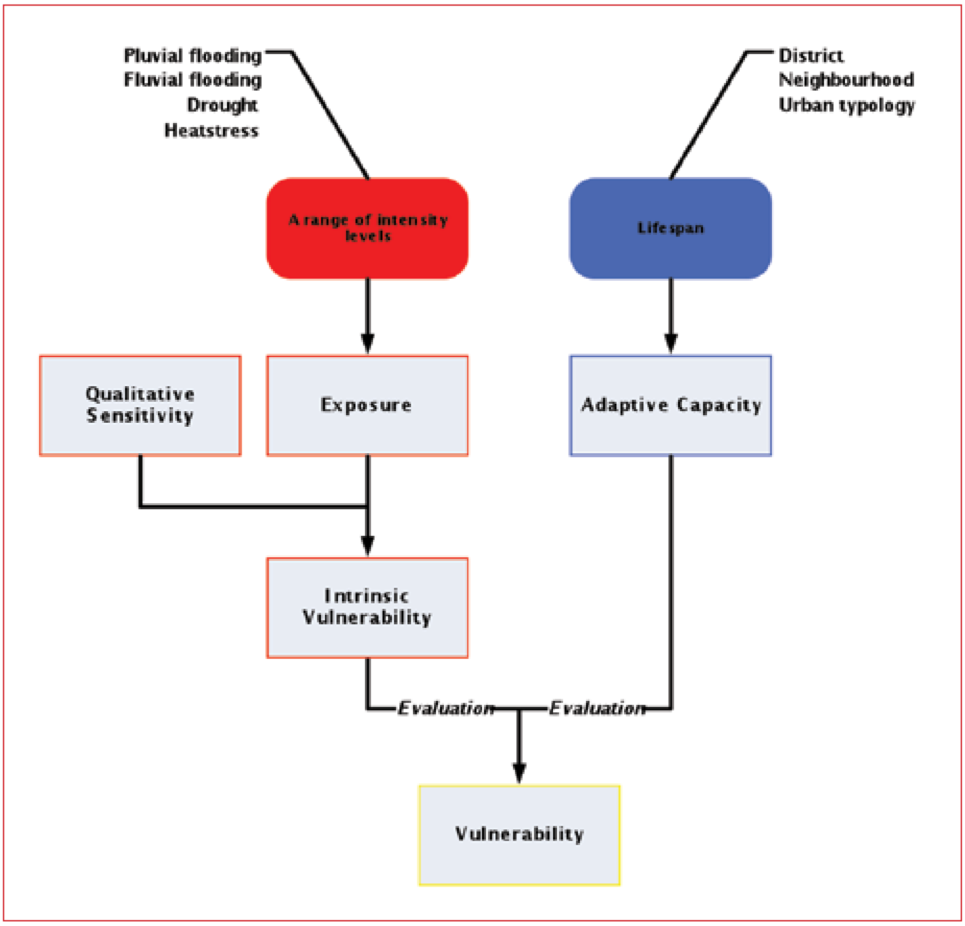


Figure 3.2 Conceptualization of vulnerability

3.3. Selected climate hazards

Climate change has an effect on the temperature which in turn has an effect on the water cycle. Although the consequences cover a wide range of effects, a subset of natural hazards has been selected that seems applicable and important for Dutch urban areas. These are:

1. *Fluvial and Coastal flooding* which has a direct effect on water safety aspects;
2. *Pluvial flooding including groundwater interaction* which creates water nuisance (puddle formation and small scale flooding);
3. *Drought* as a function of ground water shortage which results in additional land subsidence, damage to historical buildings and loss of vegetation;
4. *Heat* which contributes to health risks and economic losses.

Before jumping to the conceptualization to assess the impact of these consequences, it is important to describe the relevance of these natural hazards within the urban environment.

3.3.1. Water safety (fluvial and coastal flooding)

The Netherlands are susceptible to coastal flooding and fluvial flooding from the main rivers and regional waters. The effect of climate change on water safety is two-fold. Climate change may have an effect on the sea levels as well as on the river discharges. A trend of rising sea levels has already been observed. Also heavier and more frequent storms are expected resulting in temporary high sea levels along the Dutch coast. These temporary high sea levels are in addition to the trend of sea level rise. The trend of increasing sea levels also has an effect on the daily river levels in the lower reach of the main rivers which are in open contact with the sea. In these parts of the rivers, areas unprotected by dikes are found which are mainly in use for industry, shipping and as residential areas. An increase in rainfall is foreseen as a climate change effect as well, resulting in more frequent extreme discharges with longer durations effecting both the main rivers as well as the regional waters. In addition the higher sea levels can result in a tempered river discharge capacity during extreme discharges.

The Netherlands is protected against flooding through an extensive system of flood defences which have been constructed over the last centuries. Until recently, the main focus has been on flood prevention. Hardly any attention has been given to measures which reduce the impact of a flood through either spatial planning or event management. In the National Waterplan 2009-2015 (December 2009), it is stated that although the prevention of flooding has the first priority, attention will also be given to reducing the impact of flooding. This study explores the 'what if a flood would occur' situation and looks into strategies to prepare for such a situation. Emphasis is given on structural measures which can be taken on an urban scale. Strategies and measures to be taken on a larger scale are dealt with in the parallel study 'overstromingsrisico's en droogterisico's in een veranderend klimaat' (Klijn et al, 2010).

This study looked at the vulnerability to flooding from the main rivers and the sea (primary dikes) and to a lesser extent from regional waters. Flooding of non-protected areas were not considered as these will be extensively studied by the Knowledge for Climate projects, hotspot Rotterdam.

3.3.2. Water nuisance

Pluvial flooding is defined as flooding that results from rainfall-generated overland flow, before the runoff enters any watercourse or sewer. Urban pluvial flooding arises from high intensity 'extreme' rainfall events. In such situations urban underground sewerage/drainage systems and surface watercourses may be completely overloaded (NERC, 2008). Within The Netherlands, it is highly unlikely that pluvial flooding of urban areas ends up in dangerous flash floods resulting in casualties, injuries and structural collapse. The combination of morphology (cities are located in mostly flat areas) and moderate precipitation levels will even in extreme events only lead to the flooding of basements and damages in household inventory on ground floor level as well as traffic interruption due to flooded tunnels and roads. Nevertheless, urban pluvial flooding should be treated seriously. Over the years, the accumulation of relatively small local events has resulted in substantial aggregate damages (Ten Veldhuis, 2009). These are often underestimated since not all municipalities keep structured records of individual cases. Furthermore, since damages to individual households are minor, claims to insurance companies hardly stand out.

When groundwater levels in urban areas are structurally too high, groundwater nuisance occurs. This will lead to damage to urban functions in different ways:

- Most of all, dynamic ground water levels can cause problems of subsidence. Especially older buildings, including many monuments, are built on top of relatively fragile foundations. These require a mechanically stable environment to prevent tears within facades or bearing walls;
- The groundwater may enter crawl spaces or basements of buildings. Damp will rise and cause the forming of fungus in the living space. This may cause health problems and damage to the building;
- Plants and trees in exposed in (public) gardens might suffocate when the groundwater reaches the root zone;
- Softening of the road bed caused by high groundwater levels and subsequent freezing causes damage to the top cover of roads.

3.3.3. Drought

Drought can have an impact on different urban functions. Drought can cause depletion of the water in the root zone. This will subsequently result in the loss of vegetation and cause damage to city parks. In the clay and peat areas of The Netherlands, extended drought may cause an increase in the naturally occurring land subsidence (shrinking of clay and peat due to groundwater drainage). This causes damage to some historical buildings. Furthermore, many historical buildings in the clay and peat areas are founded on wooden foundation piles. Damage to these piles related to the structural lowering of the groundwater table will cause damage to the buildings (see Chapter 4). Apart from buildings, also roads are vulnerable to subsidence resulting from drought. While many highways in The Netherlands are built on elaborate foundation structures that can withstand significant amounts of mechanical stress, many secondary roads are built on limited base layers. Brick roads that populate many of the historial centres are generally laid-out on top layer consisting of sand packet. Finally, subsidence can also result in damages to subsurface structures. While electricity and telephone communication lines are constructed using flexible tubes, most storm water drainage networks are constructed out of concrete. Land subsidence leads to cracks and leaky fittings between drainage tubes. Furthermore, the tubes for the drinking water networks are generally made out of metal.
Although able to withstand some mechanical stress, fittings might break and lead to significant local flooding. Finally, drought can have a negative impact on the water quality of the urban (surface) water system.

3.3.4. Heat

Figure 3.3 illustrates that temperatures are substantially higher in cities than in their surrounding rural areas. This effect is called the Urban Heat Island (UHI) effect (e.g. Rahola et al. 2008). At night, the UHI effect is the largest because the cities cool much slower than their surroundings. This phenomenon is caused by:

- A higher absorption of solar radiation by paved surfaces in the city compared to vegetation, unpaved soil and water. This leads to a reduced cooling effect during the night;
- Reduced cooling through evapotranspiration, caused by the presence of less vegetation and surface water in cities;
- Reduced cooling through wind, caused by barriers such as buildings;
- Increased heating of the city through antropogeneous heat sources such as buildings and traffic.

Heat stress not only causes health effects (increased level of mortality rates and hospitalization) but also a reduction in productivity and general comfort in both public space and buildings. The 2003 heat wave, that covered major parts of Europe, resulted in an estimated 70.000 heat related fatalities (Robine et al, 2008).

Heat stress seems to be an underestimated problem in The Netherlands. In the summer of 2003, a heat wave caused 1400 to 2200 heat related deaths.. However, relatively little is known about the exact influence of the UHI effect in Dutch urban areas, because in the past measurements and models were executed mainly in rural areas. Conrads (1975) measured in 1970-1971 a maximum temperature variation of 8°C between the city of Utrecht and it surroundings.
At present, the Knowledge for Climate project HSRR05 Heat stress in the city of Rotterdam works at predicting, measuring and analysing the magnitude of the UHI effect in Rotterdam. Further studies are to be expected in the near future.

3.4. Towards an assessment model

The main objective of the methodological development within this study is to provide accurate yet meaningful results. In practise, this means a constant evaluation of trade-offs between on the one hand the level of precision and robustness of outcomes and on the other hand the usability of the results within the scope of the project. Therefore concepts that result in unreliable outcomes (e.g. indirect damages resulting from natural hazard impacts) have been omitted or described in a qualitative manner. The quantitative outcomes of this study are left relatively untouched and should therefore provide a robust foundation for future studies.

Extensive coverage of all assumptions, formalization of concepts, metrics and applied methodologies results in a

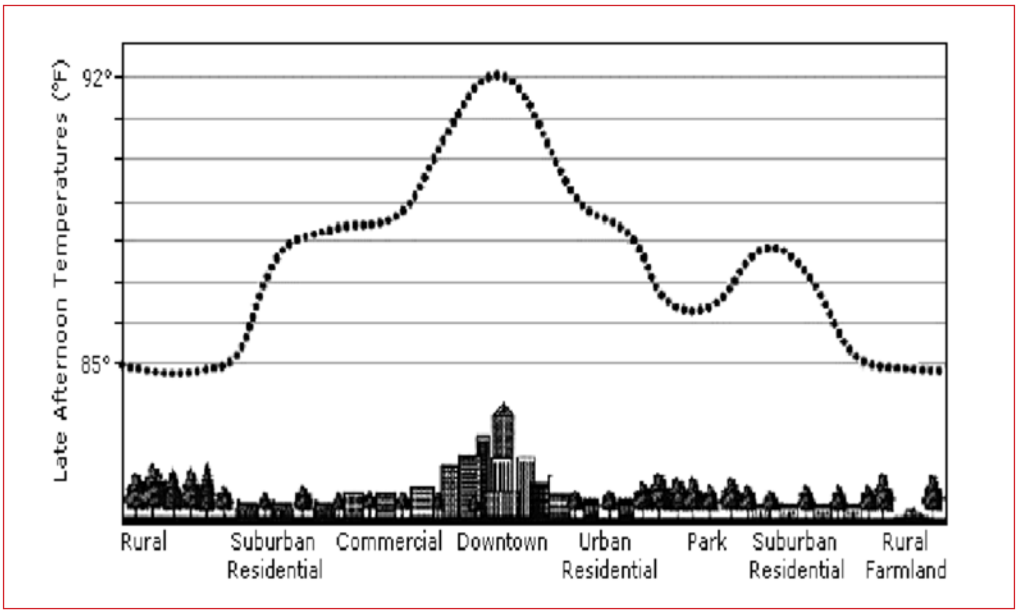


Figure 3.3 Sketch of the Urban Heat Island effect (Courtesy of Heat Island Group, LBNL)

technical descriptions including the associated terminologies. To maintain an appropriate level of readability, these are covered in appendix A.

3.4.1. Focus on exposure

As described earlier, a comprehensive vulnerability analysis for the four topics is not feasible within this study. Different modalities in sensitivity as well as inadequate models prevent a complete vulnerability assessment. Therefore, the main emphasis for the impact analysis is on the exposure of the urban areas to the described climate related hazards. The exposure is determined by combining the pathway and location of the receptor (i.e. the urban areas consisting of buildings, roads, etc.). The pathway determines how the natural hazards 'finds its way' towards the receptors. In case of pluvial flooding this is determined by storm water drainage capacity, land cover, soil composition and morphology. For every topic specific models have been used to calculate the extent and severity of the climate related hazard. These models are based on existing methodologies. For the topic of heat stress, a new model has been developed from scratch. This was necessary since no of-the-shelf models exist that are usable for the combined level of detail and coverage this study considers. The actual spatial distribution of the affected assets determines the exposure. Note that pathway and receptor to some extent overlap: while impervious land cover increase the problem of pluvial flooding by creating surface runoff, flooded roads themselves can be treated as assets exposed to flooding.

Practically, this means that exposure can be determined as follows:

- Calculation of the extent of the climate hazard effect (e.g. flood extent);
- (If applicable) Determination of a threshold level for which the effect is considered to be significant (e.g. a 10cm threshold level for pluvial flooding);
- Calculation to which extent the neighbourhood, district or other spatial unit (e.g. urban typology) is affected. This is either performed by calculating the ratio between affected and unaffected areas or by calculating the affected number of buildings.

3.4.2. Sensitivity

The sensitivity determines to what extent exposure to climate hazards is perceived as a problem. This is on the one hand determined by physical aspects (e.g. applied flood proofing measures or high threshold capacities of materials towards flood impacts) and non-physical aspects (disruption of everyday life, health risks, etc.) and on the other hand by consensus about what is considered 'acceptable'; i.e. norms.

3.4.3. Intrinsic vulnerability

The intrinsic vulnerability describes the superposition of exposure and sensitivity for the current conditions without regarding the effects of climate change or future responses. This concept differs from the conceptualization of vulnerability, described further on in this chapter, as the adaptive capacity is not taken into account. While formally no comprehensive intrinsic vulnerability assessment is made, the combination of quantitatively determined exposure and the qualitative descriptions of sensitivity provide some important insights in the actual distribution of climate related problems. Per topic, these are covered by the concept of 'intrinsic vulnerability'.

3.5. Adaptation and adaptive capacity

3.5.1. Introduction

The quality of the living environment is influenced by physical, social, ecological and economic factors. These factors could be affected by vulnerability to the urban climate. Safety, for example, could be regarded as an important factor that determines the attractiveness for investment and living in cities. The reason for climate proofing is to not only increase safety and reduce climate-induced damage, but also to benefit as much as possible from opportunities that arise from climate change (Kabat et al, 2005). Therefore, for this study adaptation is not regarded as an objective in itself, but it is presumed that adaptation is rather an opportunity to enhance the living quality of urban environments. In this Section, the starting points for the adaptation analysis of this study are described.

Cities present both the problems and the solutions to sustainability challenges (Grimm et al, 2008). Vulnerability to climate change is one of the key challenges for an increasingly urbanized world (see also Chapter 2). The vulnerability of urban areas to climate change can be reduced by mitigation and adaptation (Figure 3.4). Mitigation measures and strategies that are implemented in urban areas aim to reduce climate change by reducing carbon emissions. Therefore, they are directed at reducing vulnerability at the source. Adaptation measures are directed at reducing the consequences of climate effects. In paragraph 3.1 it is described that intrinsic vulnerability is determined by the hazard of the climate, the exposure of the city to the

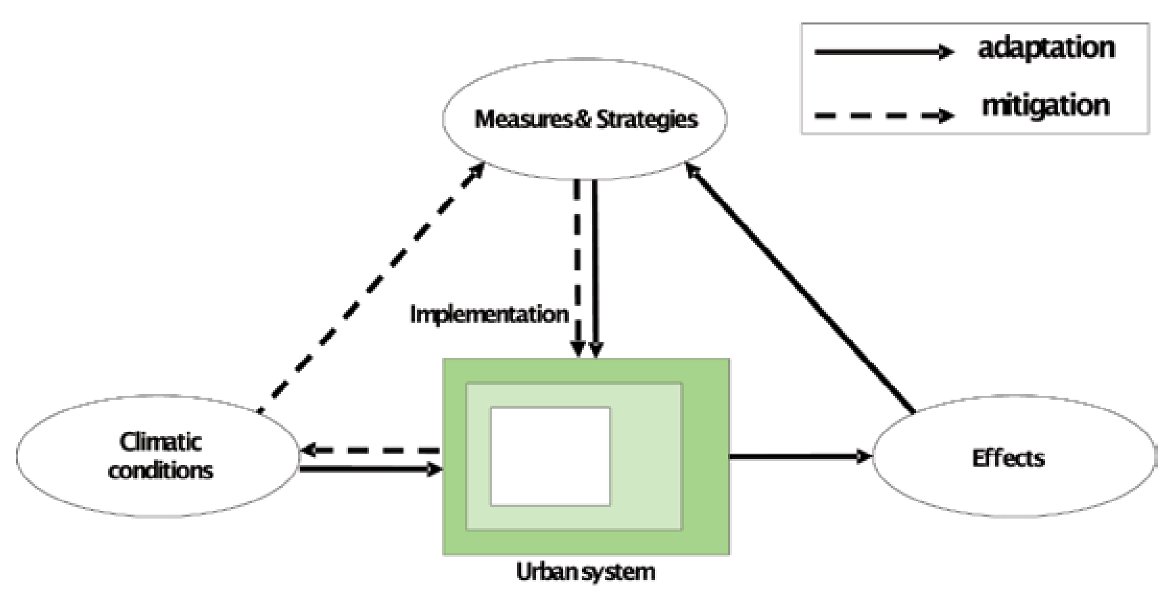


Figure 3.4 Schematic overview of adaptation and mitigation in urban systems (Rijke et al (2009))

effects of the climate and the sensitivity of the city to these effects. Climate adaptation aims at reducing the exposure and/or the sensitivity to climate change in order to prevent or cope with the effects.

This study only deals with adaptation. However, adaptation cannot be dealt with without keeping mitigation in mind because synergetic or adverse effects could emerge. Synergy between adaptation and mitigation takes place when adaptation measures also contribute positively to reduction of carbon emissions. For example when air-conditioning systems are replaced by natural ventilation systems. However, adverse effects can also occur. For example when adaptation measures require fossil fuels energy as is the case for many heating and cooling systems and water pumps. In this study, relations between adaptation and mitigation are qualitatively described to a minimum extend. High public awareness and sense of urgency about carbon-emissions and mitigation could possibly be an opportunity for coupling adaptation to mitigation measures. For further research it is recommended to study the relation between adaptation and mitigation and the opportunities that mitigation could offer for coupling adaptation in more detail.

In this study, spatial maps of vulnerability and adaptive potential form the basis for adaptation building blocks. Therefore, adaptation is limited to physical adjustments in different spatial and temporal scale levels of urban areas. 'Soft' measures have been left outside the scope of this study, because they often cannot be distributed on a spatial map. Adaptation is often described as a 'governance' problem instead of a technical or an 'engineering' problem. The spatial vulnerability assessments and technical adaptation measures should therefore be regarded as a first step to constructing adequate adaptation measures. These measures need further study on behavioural adjustments, processes, governance and other institutional arrangements.

3.5.2. Adaptive potential in space and time

Adaptive capacity and adaptive potential

Many definitions of adaptive capacity co-exist. Based on a literature review, Brooks (2003) defines adaptive capacity as the ability or capacity of a system to modify or change its characteristics or behaviour to cope better with existing or anticipated external stresses. PBL (2009) complements this definition with the societal reaction time in relation to the rate and predictability of the effects of climate change. The societal reaction time depends on the biophysical, socio-political and economic conditions and the institutional capacity to realize required system modifications. According to PBL (2009), adaptive capacity depends on the means (financial, institutional & social capital and knowledge) and opportunity (socio-political willingness, institutional arrangements and physical conditions) to adapt. Several key factors that determine the adaptive capacity are: the quality and age of the built environment; the financial rate of return of adaptation investments and modifications;

the socio-political willingness to act; and supportive institutional arrangements.

In this study, only the physical aspects of adaptive capacity are researched. The expected end of lifespan of the existing building stock and the renewal cycles of building stock are modelled (see Appendix A). To distinguish the physical potential for adaptation from the more general term adaptive capacity, we introduce the term adaptive potential. Adaptive potential is the physical ability of a system to modify or change its characteristics to cope better with existing or anticipated external stresses. Knowledge about the adaptive potential of the built environment is important for developing adaptive strategies against minimum costs, because it allows for maximum use of opportunities that emerge from ongoing urban dynamics.

However, other aspects of adaptive capacity such as finance, willingness to act and supportive institutional arrangements should also be used as a building block for adaptation strategies. Therefore, it is recommended to study these aspects more in-depth in a follow up of this project.

Setting the pace for adaptation
Three options for setting the pace of adaptation can be considered:

1. **Business as usual:** Maintain building and development practice and safeguard existing safety standards without adaptation to climate change.
2. **Active adaptation:** Use predicted climate change as the key driver for adaptation, regardless existing urban dynamics.
3. **Opportunistic adaptation:** Link adaptation to existing urban dynamics and plans to maximise the use of 'free rides'.

In reality climate change is only one of many aspects in the urban environment (next to for example safety, economics, transport, social issues, public health and ecology) that influence decision-making processes in urban development. At present, climate change is often not being regarded as the key driver for urban renewal. More often, urban renewal is the result of political or investment decisions and driven by factors such as spatial pressure, the quality and age of the building stock or social deprivation of urban areas (Knowledge for Climate 2009a, 2009b). In other words, the quality of the living environment is the leading factor for developing adaptation strategies. Active adaptation is therefore needed when safety standards of living and working areas in The Netherlands can no longer be safeguarded.

In all other cases, opportunities that arise from autonomous ongoing urban dynamics should set the pace of adaptation. Under all scenarios, predicted future climate conditions require adaptation on the long term. However, uncertainty about the pace of climate change and the sensitivity of urban areas makes it difficult to predict when measures should be in place. This gives way for an alternative approach that optimally takes advantages of free rides that emerge from ongoing autonomous urban dynamics, such as large-scale refurbishment and renovation of neighbourhoods. In this respect, free rides bring forward investments for adaptation measures that are required anyhow by combining them with investments that are planned now and by improving the quality of the everyday surroundings. This leads to synergetic effects in the construction that result in cost reduction compared to a situation where 'active adaptation' is needed. Also, one could argue that incrementally bringing forward implementation of adaptation measures increases robustness of urban areas to avoid possible future damage of uncertain climate effects.

When there is opted for linking adaptation in existing urban processes, the end of lifecycle and renewal cycle of building stock stand central. In theory, three windows-of-opportunity could open up for free-riding adaptation.

New developments in which greenfields are transformed into new urban areas give the most straightforward opportunities. In this case, adaptation measures are directly included in masterplans and designs. A similar opportunity for adaptation arises when existing urban areas are renewed or replaced by other functions[1]. Finally, renovation could offer the opportunity to reduce the vulnerability of buildings and neighbourhoods to water nuisance (e.g. water retention on green roofs), flooding (e.g. higher placement of electricity), drought (e.g. water efficient appliances) and heat (e.g. isolation and ventilation). Social housing corporations use a 25-year period for such large-scale renovations.

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[1] Please note that also urban shrink could be regarded as urban renewal: living and working functions are replaced by other functions such as recreation or amenity. However, it should be noticed that it could also be the case that urban shrink reduces the number of functions, and reduces the intensity of use of the same functions (e.g. reduced population could lead to empty apartments in a living block.

To assess the magnitude of opportunities for free-riding adaptation, potential adaptation moments have been modelled, based on the age and refurbishment cycles of building stock (see Appendix B). Assessment of new developments requires urban growth models and is outside the scope of this study, because this is unfortunately not feasible within the timeframe of this project. Modelling of refurbishment cycles contains significant uncertainty and error margins because the decision for refurbishment or renovation is not merely based on technical conditions or economic value, but it depends on a wide range of possible other factors such as investment opportunities, market conditions, socio-political aspects etc. Alternatively, windows-of-opportunity could be identified through the 'Nieuwe Kaart van Nederland' that gives an overview of urban development plans. However, this map only shows developments until ca 2025.

A large number of scientists argue that adaptation should be cultivated within existing policy frameworks in order to be effective (e.g. Brown and Clarke, 2007; Ashley et al, 2007; Van de Ven et al, 2009). Therefore, existing policy on urban planning, water management, infrastructure, commercial areas etc. is chosen as a starting point for adaptation as well (see Chapter 6).

3.5.3. Measures for adaptation

In international literature a large number of adaptation measures for reducing vulnerability to water and heat in urban areas are listed (see for example Van de Ven et al (2009), Rahola et al (2009), Van Drunen and Lasage (2007)). This study gives recommendations for adaptation options in relation to the characteristics of vulnerability (primary focus on exposure and impact) and adaptive capacity of neighbourhoods and cities. In all cases, more in-depth study is required to give location specific recommendations for adaptation options.

In this study, adaptation measures in urban areas are being categorized in four types of adaptation options (see figure 3.5). Category 'Built elements' includes all buildings and infrastructure that are located above and underground in urban areas. Category 'Ecology' includes all green and aquatic living environments in urban areas. Category 'Soil' includes soil types and ground level profiles. The category 'People and business' includes adaptation measures that are directly aimed at influencing behavioural change of people and businesses. In this study, the scope is limited to 'Built elements', 'Ecology' and 'Soil', because 'People and business' only consists of 'soft' measures which fall outside the scope of this study.

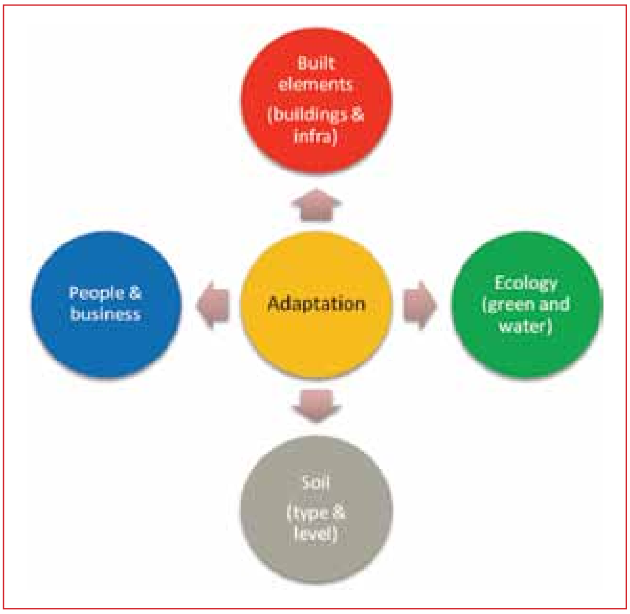


Figure 3.5 Options for adaptation measures

A long list of potential adaptation measures for flooding, water nuisance, drought and heat is categorised in Appendix B. Three main categories are defined that are equivalent to the physical static elements and non-physical elements of cities: modifications to buildings, infrastructure (both above and underground) and other public open space such as green and water bodies.

De Graaf et al (2008) have determined four system capacities that can be distinguished to withstand perturbations:

- The threshold capacity to prevent exposure to climate perturbations;
- The coping capacity to deal with perturbations when they take place;
- The recovery capacity to recover from perturbations after they have taken place;
- The adaptive capacity to anticipate change of climate vulnerability on the long term.

For each category a distinction is made between the contribution of an adaptation option and the threshold or coping capacity of cities. The recovery and adaptive capacity have not been taken into account. In this study, adaptive capacity is used as a starting point for selecting adaptation options in order to add a temporal dimension to the threshold, coping and recovery capacities. Therefore, we will not elaborate further on adaptive capacity in this section (see also previous section). Physical elements can only increase the threshold and coping capacities of cities, while non-physical measures can only increase the coping

(and recovery) capacities of cities. Maps for vulnerability and adaptive potential of cities and neighbourhoods are used as a base for selection of suitable adaptation options. The smallest scale level that can be achieved here is the scale of neighbourhoods. However, based on cartographic material of this scale it is very difficult to create selection scripts of non-physical measures, because they are either at a more local level, or either evenly distributed over complete cities of even countries.
Therefore, non-physical adaptation measures unfortunately fall out of the scope of this study. Because recovery capacity is only based on non-physical measures, it is excluded for this study as well. It is recommended to elaborate on non-physical measures and recovery capacity in a follow-up of this project.

3.5.4. Selection of adaptation measures

Selecting adaptation measures is a political decision. Moreover, it is always based on local conditions. This study does not attempt to make this decision, but it will provide general support for selection decisions. From the vulnerability assessment and the adaptive potential, adaptation measures can be selected that are suitable and applicable. Unfortunately, such a general approach is not suitable to make a location specific selection between measures, because it neglects for example socio-cultural, political and financial design parameters.

For the selection of a range of adaptation options that could address vulnerability and are in line with the adaptive potential of a certain neighbourhood or city, the following criteria are used in the KBNL2 study:

- Effectiveness or level of climate proofing of options (%);
- Cost/benefit (Euro);
- Spatial claim (ha, permanent/temporary) and scale;
- Quality of living environment (healthy, safe, liveability);
- Interaction with mitigation (should be addressed only marginally where possible);
- Effect to other policy themes and trends;
- Flexibility (e.g. spatial claim to keep options open in future);
- Time (Implementation time, life cycle duration, time to effect);
- Robustness to range of climatic conditions;
- Synergy in different field (especially interaction between rural and urban areas);
- (Social) distribution.

The current state of the art and the available time for this study are insufficient to precisely address all these criteria for all identified measures. Rijke et al (2009) have identified that current scientific knowledge is not sufficient to quantitatively determine the effectiveness of adaptation measures in real urban designs. It is unlikely that such knowledge will become available, because the uncertain complex dynamics in urban environments makes climate adaptation a 'wicked' problem for which no permanent solutions exist (Rijke et al, submitted).

However, in order to give support to the selection of adaptation measures, it is chosen to use a qualitative approach in this study. All measures are assessed on their ability to reduce different types of vulnerability by increasing either the threshold or coping capacity of urban systems. Synergetic and adverse effects between different types of vulnerability and between adaptation and mitigation are qualitatively assessed.

Besides the impact of measures in relation to climate adaptation and mitigation, the cost of measures is being considered as a key factor for decision making. During this study it became clear that there is insufficient knowledge about cost-benefit ratios of adaptation measures. There are several reasons for this. Firstly, benefits of adaptation are mainly to be sought in avoided damage cost. Scientific literature distinguishes direct and indirect damage. In particular for predicting and determining indirect damage there is a large knowledge gap in literature. Secondly, both costs and benefits are heavily depending on local conditions and externalities. These are beyond the scope of this study.

Alternatively, the 'minimum increased cost potential' of adaptation measures is qualitatively being described. In this approach, the cost for a conventional development is compared to a similar development that includes a certain adaptation measure. When the realisation of a development with the particular adaptation measure is in theory equally expensive, we speak of zero or no increased cost potential. When the minimum cost increase is relatively low or high compared to a conventional system, we speak of respectively low and high increased cost potential. Because of the limited resources of this project, the distinction between no, low or high increased cost potential is arbitrary and based on expert judgement. More in-depth research on this aspect is recommended for a follow-up of this study.

Subsequently, the regret-potential is determined based on the impact and minimum increased cost potential of measures. No regret measures have positive effects under all future scenarios and have merely positive side effects for reasons other than climate change. Therefore, they are favourable in climate adaptation strategies under all scenarios. When a particular measure to for example flooding has no adverse effects for other vulnerabilities, and when the minimum increased cost potential is 0, we speak of a measure with a no-regret potential. This means that the particular measure is potentially a no-regret measure. However, local conditions over time such as available space and technological expansion opportunities determine whether a particular reason is indeed a no-regret measure.

A final parameter for developing adaptation strategies lies in the responsibility for taking measures. To give insight in this factor, the number of possible measures for different stakeholders is counted. The availability of measures says something about which stakeholders could play an influential role in adaptation. However, the number of available measures does not say anything about the effectiveness of these measures and therefore the effectiveness of the response of a particular stakeholder.

4. Vulnerability of Urban Areas to Climate Effects

4.1. General

The KNMI (2006) climate scenarios predict that both winters and summers will generally be a bit warmer. Average winters will also be wetter and more extreme rainfall situations will occur. Extreme rainfall will also occur more often during the summers, but, in general, the summers will become dryer resulting in an increase of the 'rainfall shortage'. Furthermore, both the sea levels as well as the river discharges will rise. All these changes will directly or indirectly have an impact on the (ground)water system in urban areas and also on the ambient temperatures. Table 4.1 presents the expected changes for the four different KNMI'06 climate change scenarios in more detail.

It should be noted that the vulnerability is mainly determined by the occurrence of extreme events (e.g. extreme rainfall, storm events or long periods of drought) and to a lesser degree by the gradual change of the average climate.

Table 4.1 Climate change in The Netherlands around 2050[1], compared to the baseline year 1990[2], according to the four knmi'06 climate scenarios.

		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter	average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	coldest winter day per year	+1.0°C	+1.5°C	+2.1°C	+2.9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥ 0.1 mm)	+0%	+1%	+0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer	average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	warmest summer day per year	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥ 0.1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
Sea Level	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm

[1] *data on changes in 2100 can be found at www.knmi.nl/climatescenarios*

[2] *the climate in the baseline year 1990 is described with data from the period 1976 to 2005*

[3] *'winter' stands for December, January and February, and 'summer' stands for June, July and August*

The information provided by the KNMI ’06/’09 scenarios has been used to determine the increase of exposure of urban areas to flooding from rivers and the sea, to pluvial flooding, and to the increase in groundwater levels. The modelling methods are described in Chapter 3 and Annex C. There is no methodology available to derive a possible increase in drought and heat stress exposure based on the KNMI ’06/’09 scenarios. Therefore, we have only described the effects of drought and heat stress qualitatively.

4.2. Water safety (fluvial and coastal flooding)

4.2.1. Effects of climate change on water levels and discharges (hazard)

The Netherlands, a delta area partly below sea level, will always face a threat of flooding although over a period of time the probability of river and sea levels exceeding the level of the flood defences has been reduced considerably (ranging from 1:250 to 1:10,000 years). Flood defences protect most of the flood-prone areas. These areas are divided into so-called dike rings. Each dike ring consists of an area surrounded by a closed system of flood defences. Per dike ring, a flood safety standard has been defined.

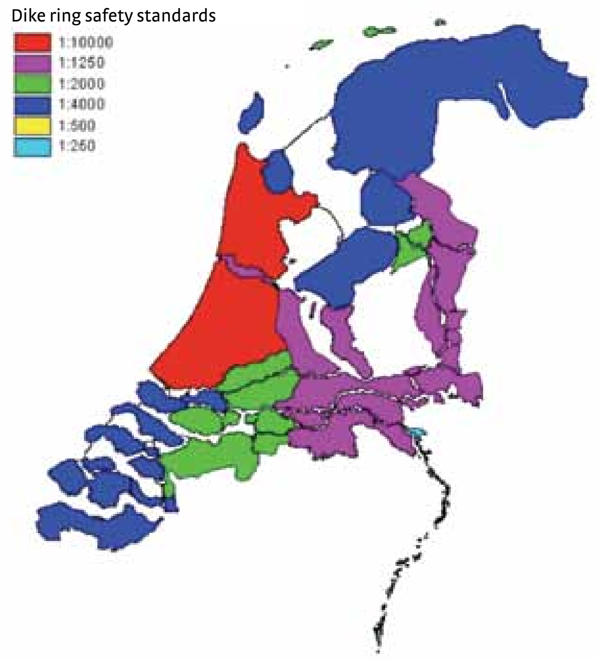


Figure 4.1 Safety standards per dike ring (wet op de waterkering, 2006)

The safety standards were defined over 50 years ago. Dike rings containing large concentrations of assets, economic activity and residents have been given a higher protection level. The safety standards are now being revised to comply with developments within the dike rings which progressed since the definition of these safety standards. The current safety standards per dike ring are illustrated in figure 4.1. What can be observed is that the western part of The Netherlands has the highest safety standards owing to the concentration of economic activity and the number of inhabitants.

For the regional waters, a similar approach has been followed, though less strict safety standards apply because of the less extensive expected impact.

It is expected that the water levels corresponding to the safety standards,will increase due to climate change. The Dutch policy is to maintain the safety standards and thus to adapt the flood defences and river system (e.g. room for the river measures) to comply with the expected increase of extreme discharges and sea level rise. It is therefore foreseen that due to climate change, extreme discharges and higher water levels will occur more frequently. By maintaining the safety standards, the probability of an actual flooding is not expected to increase.

Along the lower reaches of the main rivers there are areas – other than the winter bed – which are not protected by dikes,.These relatively high lying areas have historically been used for industrial activities and shipping. Recently, municipalities are exploring the possibility of turning these unprotected areas into multifunctional and residential areas. More frequent extreme discharge levels with longer durations in combination with sea level rise can result in increased probabilities of flooding of these areas.

4.2.2. Exposure of cities to flooding in The Netherlands

General exposure of areas to flooding

Climate change results in a sea level rise and an increased duration of extreme discharges.. So, if a flooding occurs, more flood water will be flooding into the aera resulting in a *larger flooded area (increased flood extent)*. Also, there will be *greater water depths* and thus a larger water volume. Water will accumulate in the deepest part of a dike ring. The draining of a larger volume of water will take more time and will result in an *increase of the flood duration*.

A water depth map for The Netherlands has been developed by the Directorate General for Public Works and Water management (Rijkswaterstaat) and is shown in figure 4.2. This map is a compilation of approximately 800 flood simulation results for different scenarios and shows the potential maximum water depth per location. The scenarios all simulate failing of one or more dikes during water conditions corresponding to the safety standard, thus the maximum river and sea water levels and volumes which the flood defences should be able to withstand. This map only represents the current situation. Climate change effects have not been taken into account. The scenarios also assume that stronger flood defences and other line shaped obstacles within the dike rings do not fail (although some of these defences do overflow). It appeared that especially in the coastal zones, certain areas remain practically unflooded, e.g. the Haarlemmermeerpolder. It is uncertain that these inner flood defences will withstand the pressure of the floodwater if an actual flood were to occur. Note that the extent of a single flood event will be much smaller than is shown on this map.

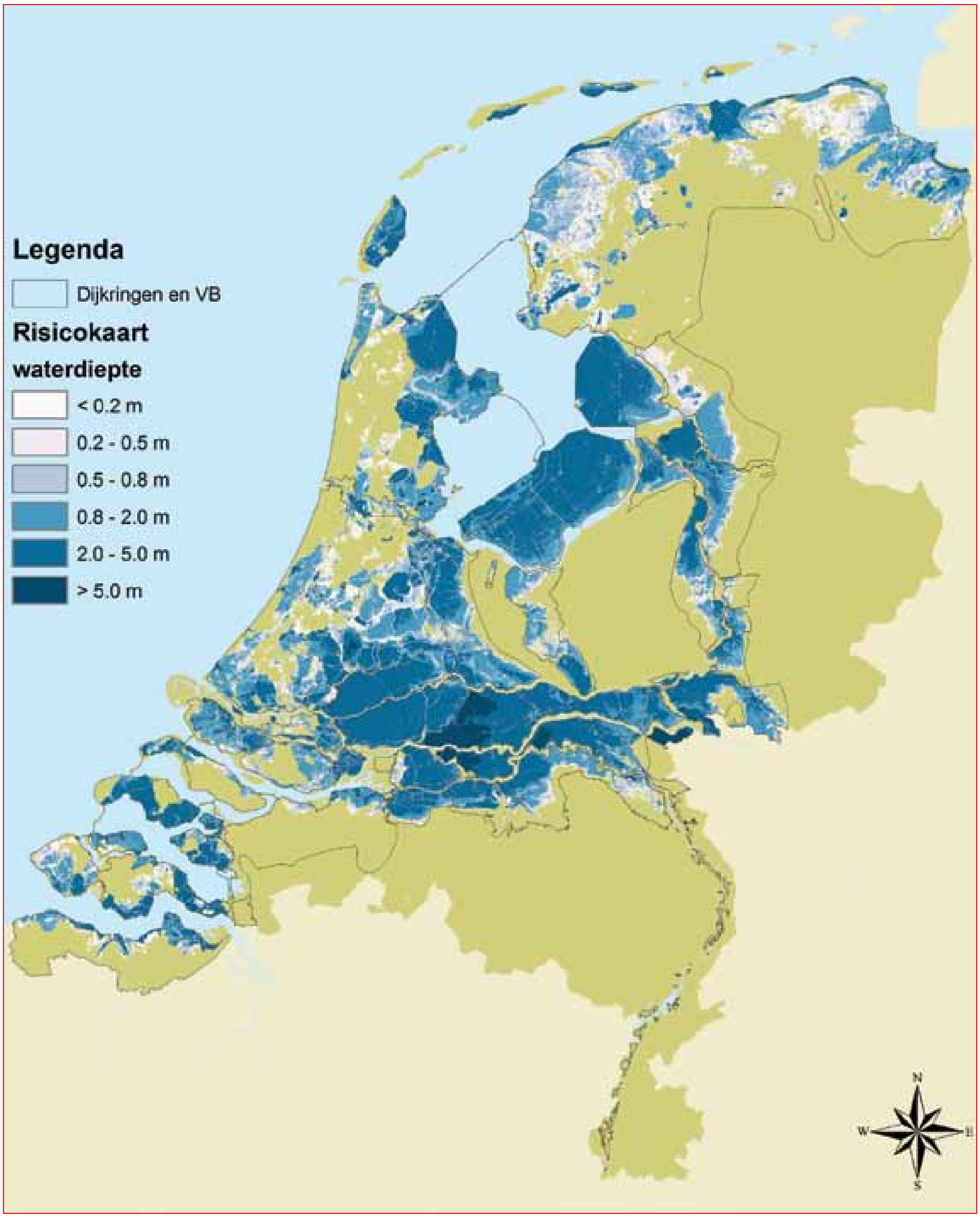


Figure 4.2 Maximum water depths (Directorate General for Public Works and Water management)

Expected area effect of climate change

Within the framework of the parallel project 'overstromingsrisico's en droogterisico's in een veranderend klimaat' (Klijn et al, 2010), an assessment has been performed on the possible effects of increasing sea level rise and river discharges on water depths. This was done by comparing the outcome of several model simulations, which have considered climate change effects.

From the assessment, an estimated increase in water depth per dike ring was made, based on the following assumptions:

- a sea level rise of 1.3m., the maximum sea level rise in 2100 according to the Delta commission (Deltacommissie, 2008) and worst-case scenario for The Netherlands;
- and no river levels rise as a result of room for the river measures.

An overview of effects of climate change per area type is shown in table 4.2.

The increase of water depth per dike ring area is illustrated in Figure 4.3. This map was used for the assessment of increased exposure of the urban area due to climate change.

Table 4.2 Summary of effects of climate change per dike ring type

Dike ring	**Effects climate change on flooding characteristics**	**Increase of water depth (m)**
Coastal areas which only flood partially (provinces of Noord-Holland, Zuid-Holland, Groningen, Friesland, Zeeland)	Sea level rise and storm peaks cause a larger hydraulic gradient which results in a larger volume of water discharging into the dike ring area. Water depth, flooded area, water volume and flood duration will increase.	+ 0.65
Small dike ring areas along the coast (including the northern islands) which fully flood	These dike ring areas flood fully under current conditions Sea level rise and storm peaks cause a larger hydraulic gradient which results in a larger volume of water discharging into the dike ring area. Water depths, water volume and duration of flooding will increase. In addition higher water levels can cause overtopping of inner dikes resulting in a larger area being flooded.	+1.3
Dike ring areas in the transition zone of coastal and river dominated floods	These smaller dike ring areas under current conditions and are susceptible to storm surges and sea level rise.	+1.3
Dike ring areas susceptible to river flooding	Along the Rhine and Meuse measures have been taken increasing the river capacity. Up to a Rhine discharge of 18,000 m3/s and a Meuse discharge of 4,600 m3/s water levels will not exceed the current safety levels. A negligible increase of water depth is expected due to an increase of the duration of high river water levels.	0
Dike rings along the IJssel lake	The IJssel lake drains onto the sea. When sea levels rise, the water levels in the IJssel lake will increase due to the lesser possibilities to drain onto the sea. This in turn results in a larger hydraulic gradient which results in a larger volume of water discharging into the dike ring area. Water depths, water volume and duration of flooding will increase.	+0.8 – +1.1

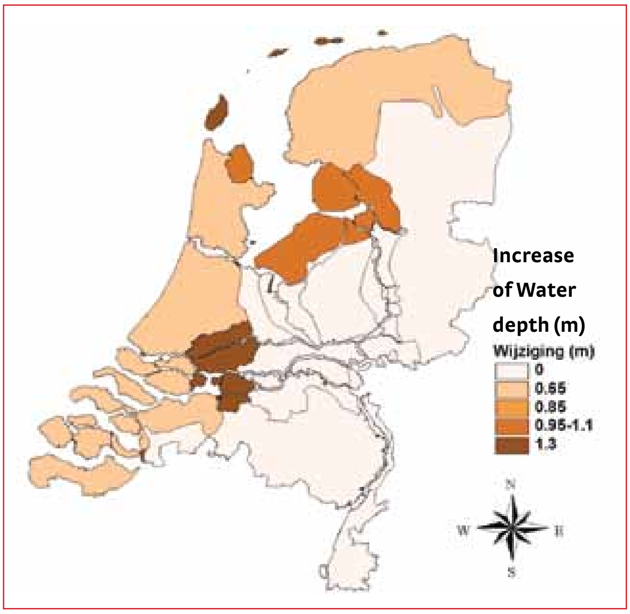


Figure 4.3 Results of assessment on increase of water depth per dike ring for a sea level rise of 1,3 m and no river level rise

It is important to note that this assessment only studied the effects on water depths. It did not look into the effects of a possible increase of flood extent. This effect could occur especially with the larger dike rings for which it is assumed that they will only flood partly (provinces of Noord-Holland, Zuid-Holland, Groningen, Friesland, Zeeland). Overtopping of the inner flood defences (assuming these defences do not breach) could cause flooding of areas which currently are presumed to remain dry. This is illustrated by the flooding map for the worst credible flood for the coastal area (figure 4.4). This map illustrates the threatened area for a storm surge scenario with a probability exceeding the safety standards by a factor 10. The flood simulations which underlie the map, assume no breeching of inner dikes (Kolen and Wouters, 2007).

The concern for flooding by breaching of a regional dike has grown since the collapse of the Wilnis dike., Safety standards have been assigned for the regional flood defences similar to the primary flood defences, in accordance with the economic value and the number of inhabitants these defences are protecting. The water depth map for the Province of South-Holland (figure 4.5) presents a first impression of the impact of a possible regional dike breach. There is no information readily available for other Dutch areas. The map of the province of South-Holland is a composition of flood simulations results. It shows the potential maximum water depth as a result of breaching of flood defences for a 1:1000 year situation. Note that the extent of a single flood event will be much smaller than is shown on these maps. These maps have been made using relatively simple models and give a first impression of the possible impacts of flooding. Currently, the water boards are developing improved flood maps with the use of higher quality models.

This map shows that if a flood defence with a safety level up to 1:1000 years would fail, water depths larger than 1 metre can be expected, especially in the 'Veenweidegebied' (triangle Vinkeveen, Alphen aan den Rijn, Aalsmeer) and north of Zoetermeer.

When comparing these results to the river and coastal floods water depth map, it appeares that areas which are expected to remain unflooded in case of a river or coastal flooding, could actually flood if a regional flood defence fails. This is illustrated in Figure 4.5.

No research has been executed yet on the effects of climate change on regional flooding. These regional waters are the draining system for the surrounding area. High water levels within the system are reached after a period of extensive local rainfall. It is expected that rain intensity and frequency will increase due to climate change. No full insight is available yet to what extent the regional drainage system is capable of coping with these effects of climate change.

Exposure of urban area to flooding

Research on flood vulnerability has mainly focused on the present situation and on the scale of a dike-ring. For the dike-rings, information is available on the flood characteristics e.g. flood extent, water depth, and on the impact such as the foreseen damage and victims. The specific exposure of the urban area to flooding has not been studied yet.

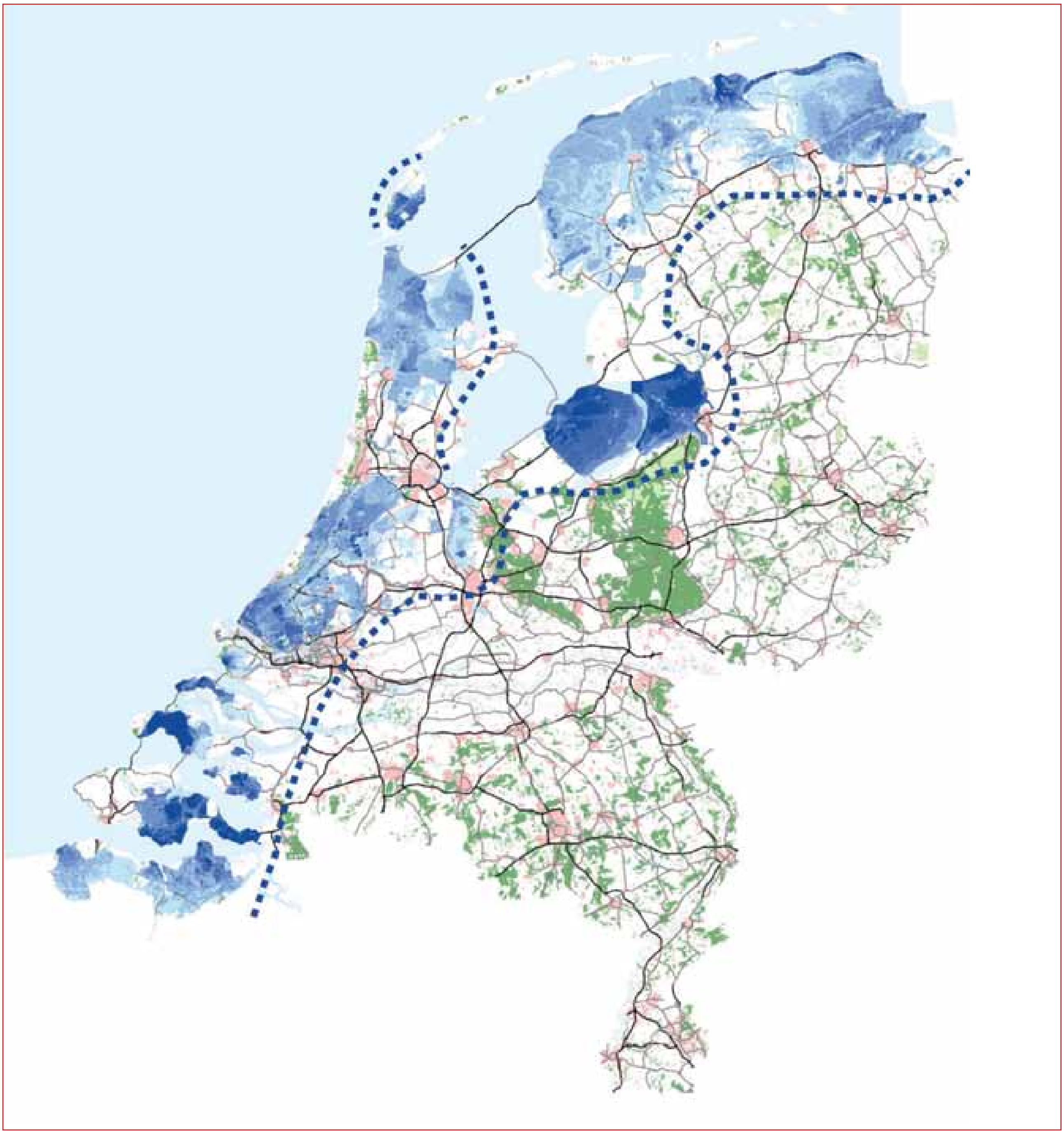


Figure 4.4 Threatened area for a storm surge scenario with a probability exceeding the safety standards by a factor 10 (Kolen and Wouters, August 2007)

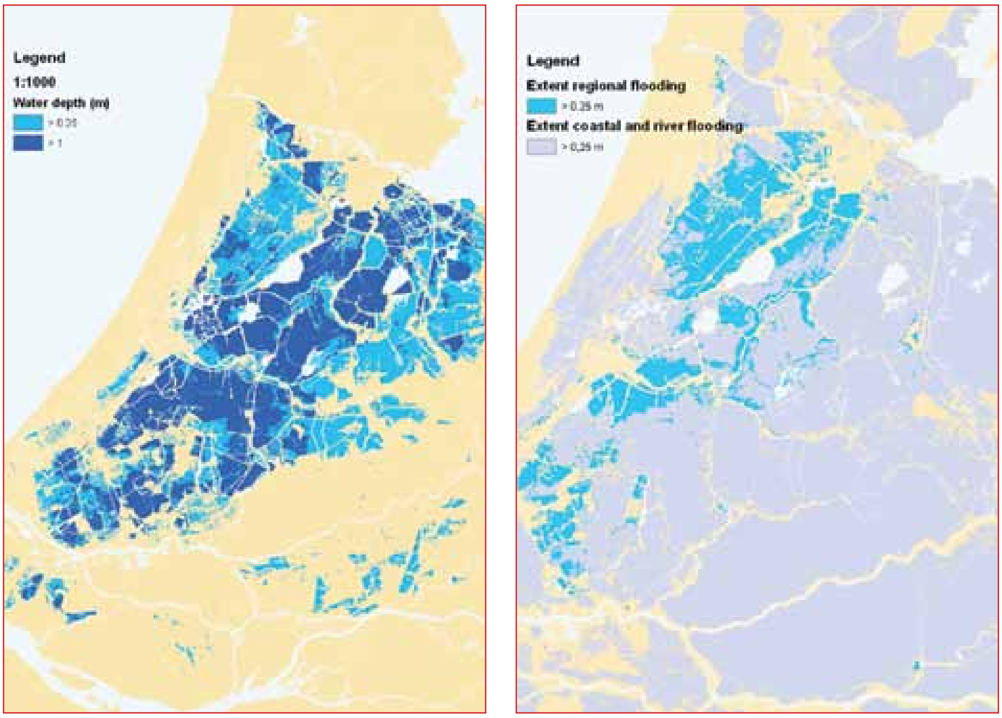


Figure 4.5 Water depths from failure of regional flood defences with safety standard up to 1:1000 years (left) and difference in floodable area (right).

Therefore the following research questions were addressed:

- Which cities are most exposed to flooding?
- Can urban typologies be identified which are more exposed to flooding?
  - Which urban functions are most exposed to flooding?
  - Are urban areas of a certain age more exposed to flooding then others?
  - To what extent is the Dutch cultural heritage exposed to flooding?

The following paragraphs examine the exposure of the urban area to flooding for the present situation. Paragraph 4.2.5 evaluates the possible climate change effects on the urban area.

General exposure of cities to flooding

To gain an impression of the exposure of the main cities, the percentage of flooded area per neighbourhood was determined. The results are shown in Figure 4.6. For this study two water depth boundaries were chosen. An area is considered susceptible to flooding if the water reaches a depth of at least 25 centimetres. Up to 25 centimetres, one will experience the flood as a nuisance, comparable to pluvial flooding effects. A water depth of one metre and larger is considered to be a severe flood. This too is based on a psychological boundary. At low water velocities up to one metre one will be able to move through the water (leaving water temperatures out of account). For larger water depths it will be safer to stay out of the water.

Of the four large cities (Amsterdam, The Hague, Rotterdam and Utrecht), Rotterdam and Utrecht show a large area being exposed to flooding. For the whole of The Netherlands, it turend out that, at present, the cities within the dike rings which lie along the main rivers and IJsselmeer lake are more exposed to flooding. In these areas floods will cause large water depths. The larger cities Lelystad, Almere, Zwolle, Arnhem, Nieuwegein, Dordrecht and parts of the cities Rotterdam, Den Bosch and Nijmegen are also exposed to flooding. It should be taken into account that the safety standards differ per area and that a flood event will have an impact only on the specific flooded area.

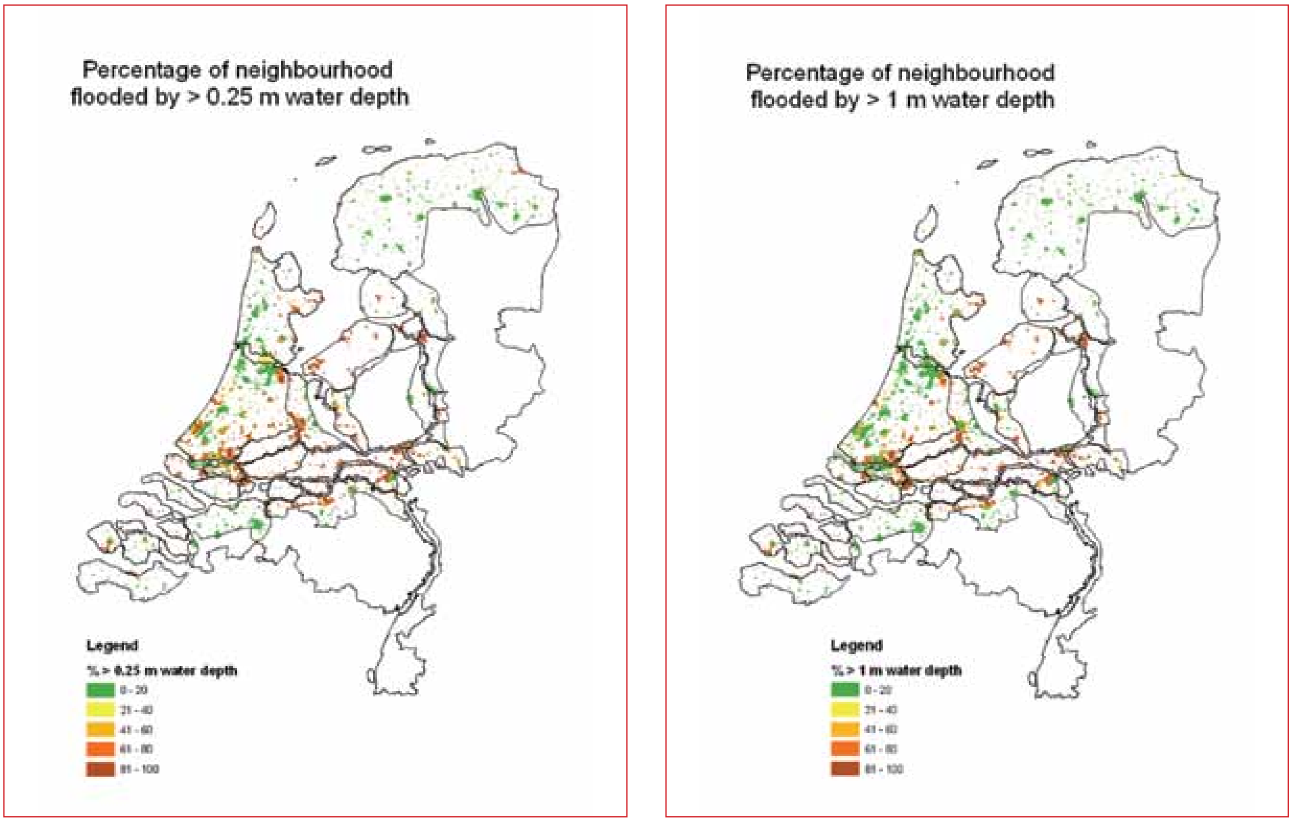


Figure 4.6 Percentage of neighbourhood flooded by > 0.25 (left) and > 1 meter (right).

Susceptibility of city functions

The way we build our cities has changed during time due to improved technical insight, changed building regulations and spatial planning concepts. Every era has therefore left a specific mark on neighbourhoods. After the Second World War there was a great demand for housing. Further growth of the population and economy increased the demand for housing, industrial areas and office areas. Building in low-lying areas on a large scale was made possible due to improved techniques. This expansion of Dutch cities onto lower lying areas has increased the flooding susceptibility of the cities.

A city is a place where many activities come together. This paragraph looks into the exposure of these urban functions to flooding. Use was made of the map on ‘Stedelijke milieus 2006’ (Ritsema van Eck et al, 2009). The 19 distinguished functions were combined into 7 main functions: Residential, Industrial, Centre, Large infrastructure, Peripheral retail trade, Offices and Public and social and cultural environment.

The impact of flooding is expetected to be extensive for the following functions:

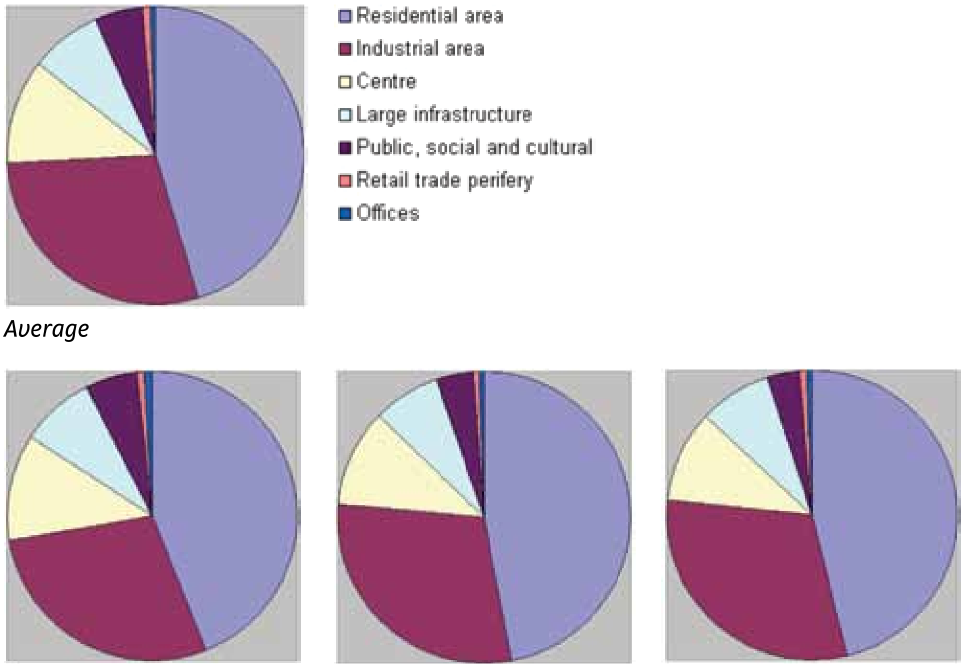
- Residential areas: Within residential areas, there will most likely be a concentration of people, especially outside working hours. In addition, high water depths and/or flow velocities can damage the houses.
- Industrial areas:,A concentration of people can be expected during working hours. This will lead to damage to buildings and machinery and to losses as a result of economic stagnation.
- City centres: In centre areas mostly a mix of functions is found. People live in the centres and this could result in casualties. Damage can occur to buildings and economic stagnation can be expected. In addition, centres often are the older areas where historical buildings and museums are situated.
- Office areas: A concentration of people can be expected during working hours, although most offices have multiple floors providing shelter. Damage could occur to buildings. Offices are often larger and thus more solid constructions. Damage will mainly be caused by economic stagnation.

Large infrastructure is also an important and vulnerable function within a city. But this function will be different per city and therefore general conclusions can not be drawn.

The distribution (area) of these functions has been compared for flood susceptible and flood free areas within the dike rings. The results are illustrated in Figure 4.7. When looking at the different functions, it appeares that the distribution of the functions does not differ greatly for the flood susceptible or flood free areas. The functions 'Residential' and 'Industrial are slightly larger in flood susceptible areas. In general, the 'Residential area' and 'Industrial area' form approximately 75% of a city area. These functions are therefore most exposed to flooding. This conclusion is based on the area distribution. In addition to these results, it is recommended to gain insight into the distribution of economic value as well.

Susceptibility of neighbourhoods in relation to age

Currently, cities are expanding to low lying areas. This is illustrated in Figure 4.8 to Figure 4.11. The development of residential, industrial and city centre areas has moved to areas susceptible to flooding. The residential areas show the largest shift to flood susceptible areas over time. It should be noted that the figures also illustrate that building in flood susceptible areas is of all times.



Average

< 0.25 cm *> 0,25m* *> 1m*

Figure 4.7 Ratio of functions for areas not exposed to flooding (0-0.25m water depth) and exposed to flooding (>0.25m water depth)

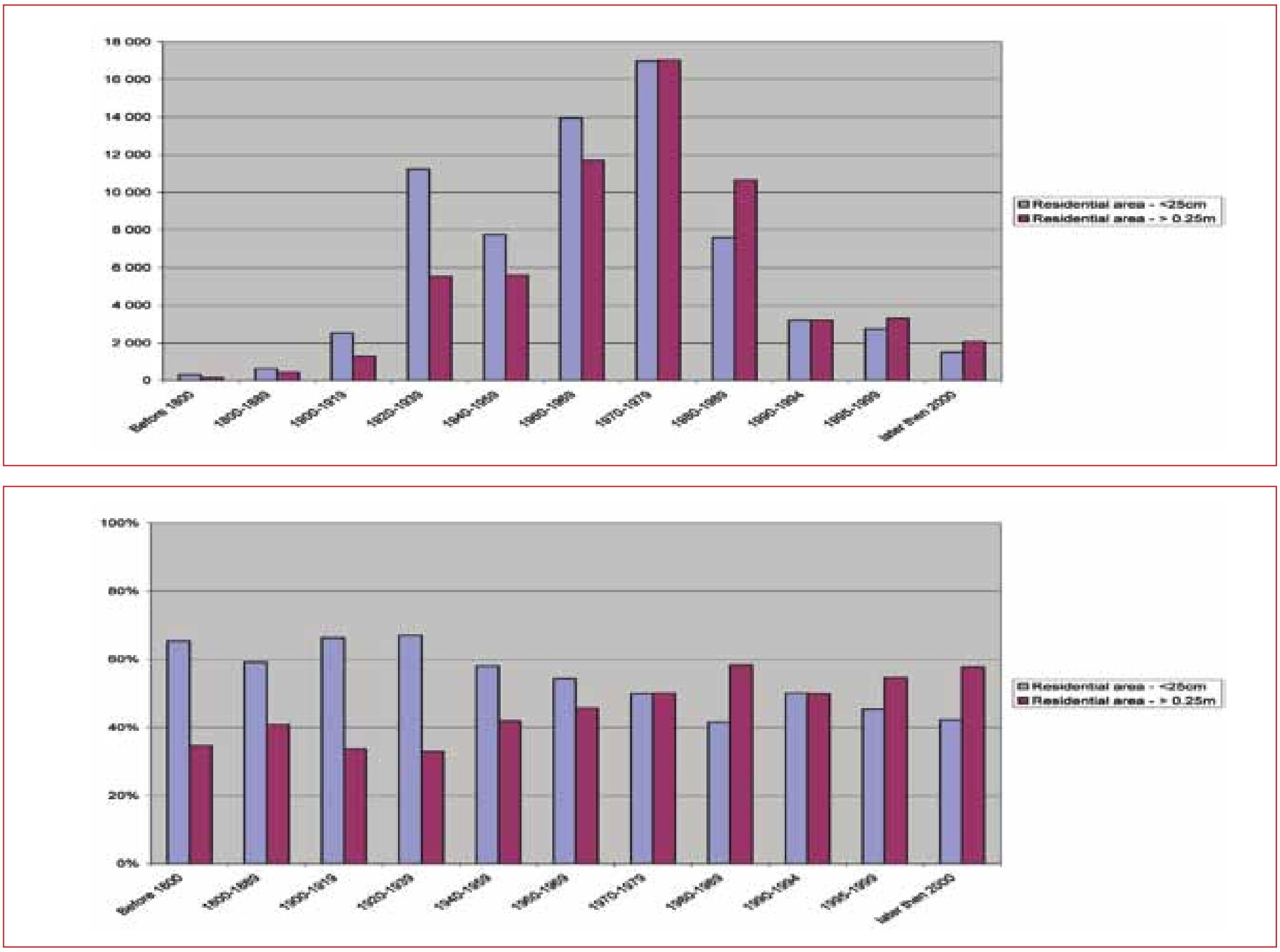


Figure 4.8 Absolute (top figure in ha) and ratio (lower figure in %) of residential function in flood free (blue) and flood susceptible (red) areas

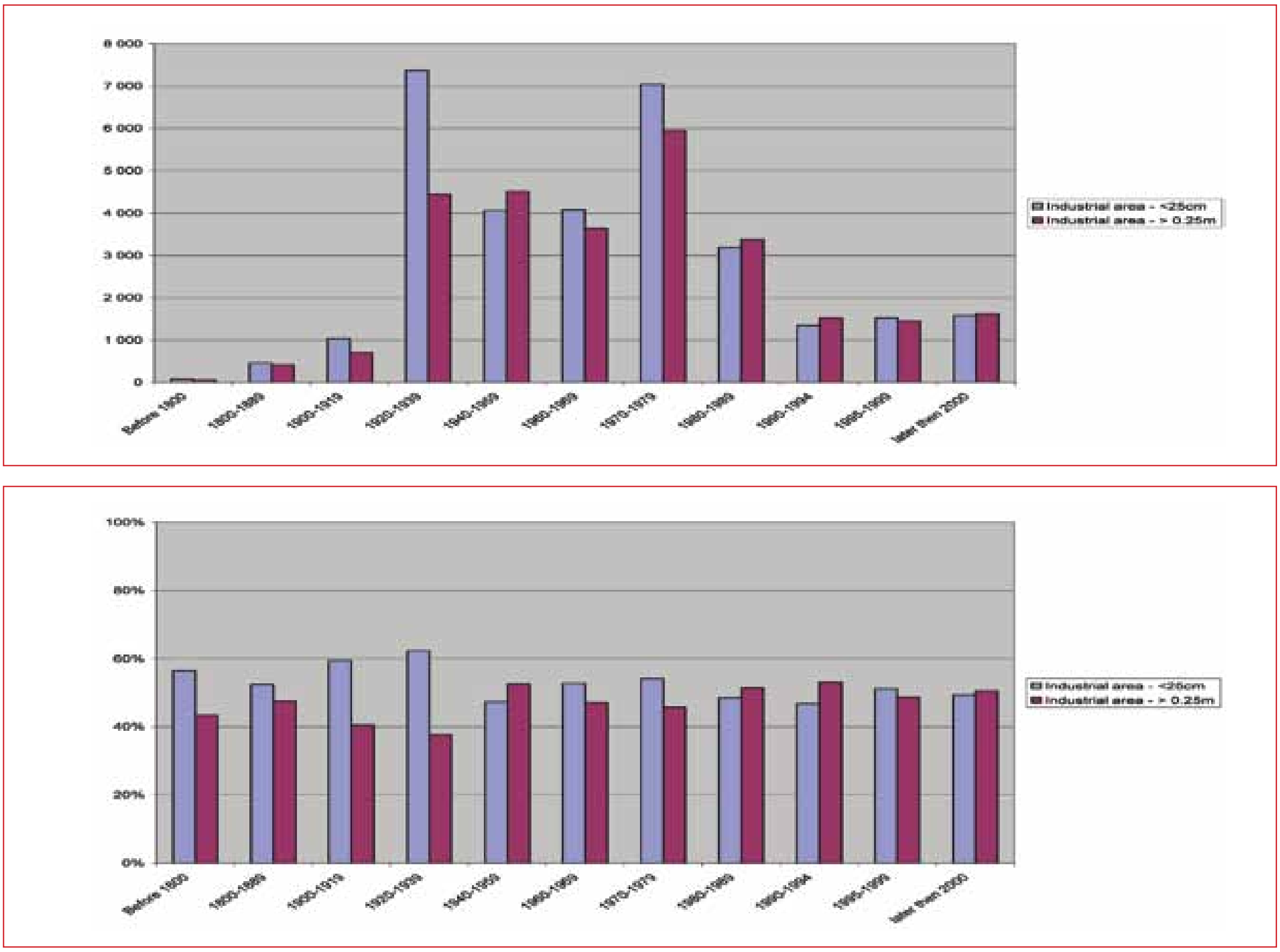


Figure 4.9 Absolute (top figure in ha) and ratio (lower figure in %) of industrial function in flood free (blue) and flood susceptible (red) areas

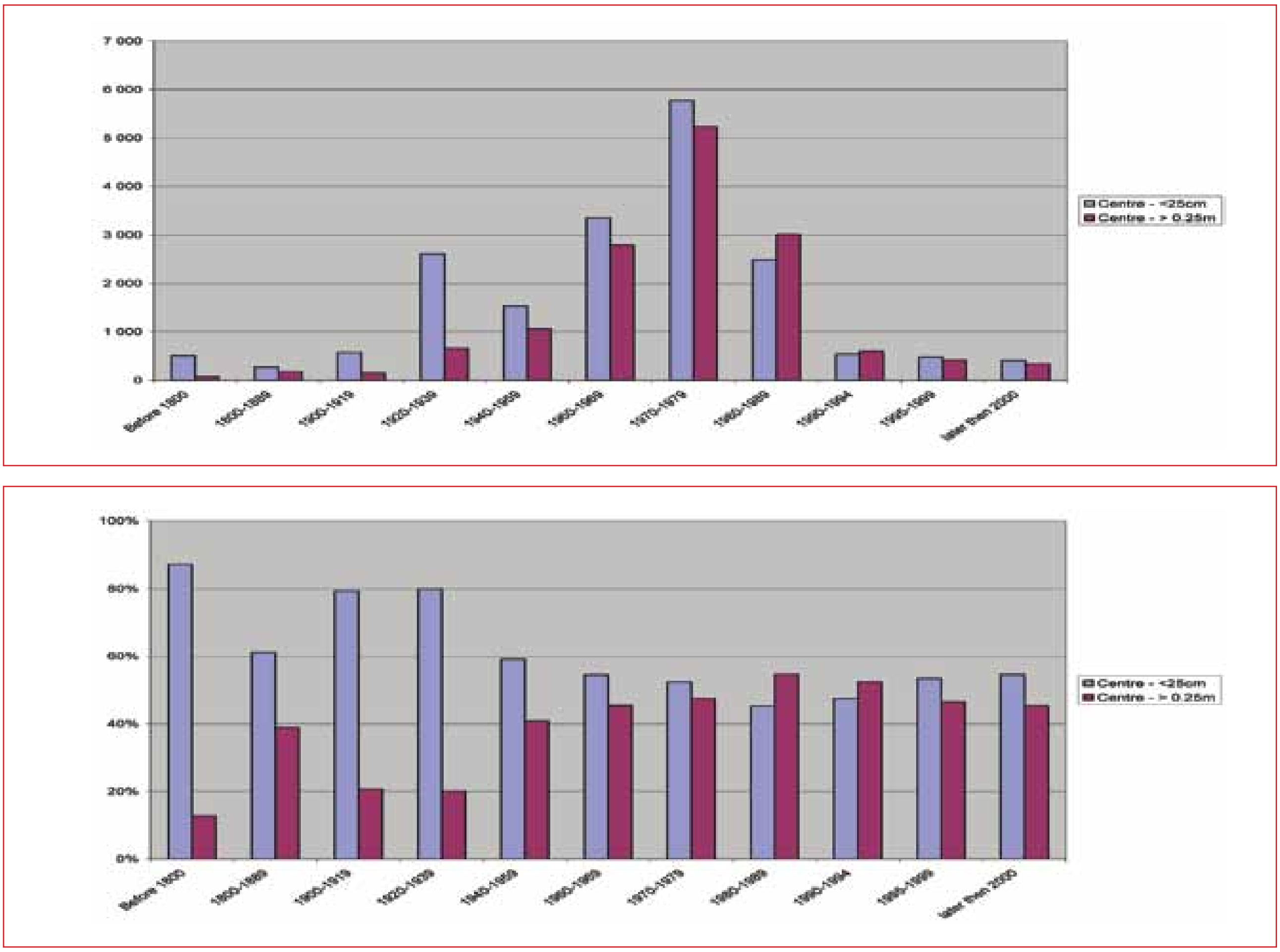


Figure 4.10 Absolute (top figure in ha) and ratio (lower figure in %) of centre function in flood free (blue) and flood susceptible (red) areas

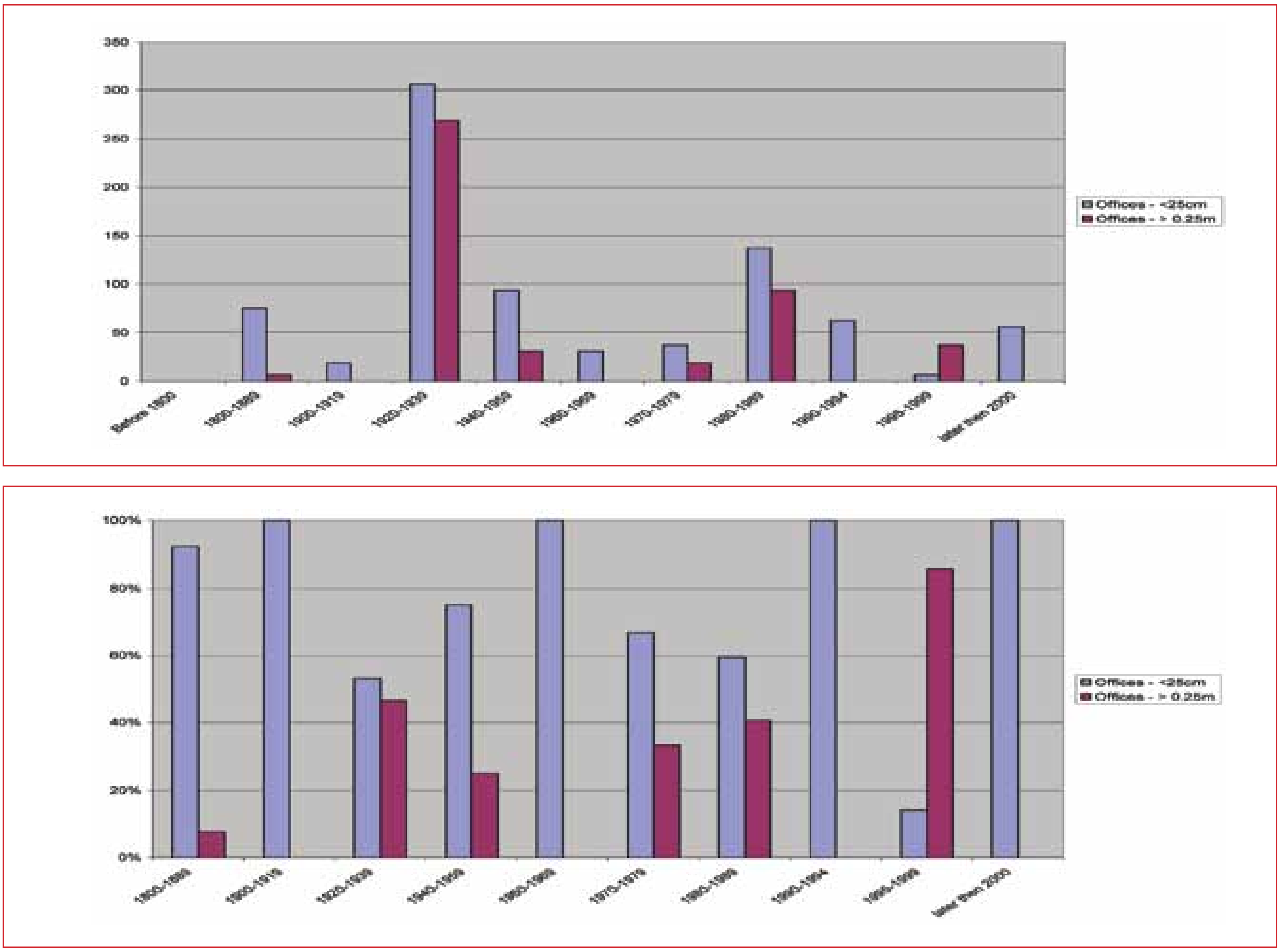


Figure 4.11 Absolute (top figure in ha) and ratio (lower figure in %) of office function in flood free (blue) and flood susceptible (red) areas

Cultural Heritage

It has always been assumed that the old city centres were built on higher grounds and therefore are not highly susceptible to flooding. These areas house many of the Dutch cultural heritage. This assumption is confirmed by Figure 4.12. This figure shows that up to 1940, city centres were mainly built in areas that are not exposed to flooding.

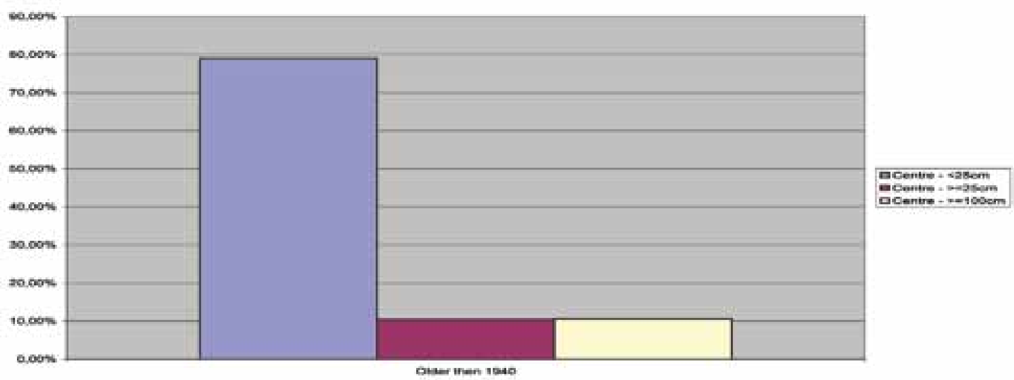
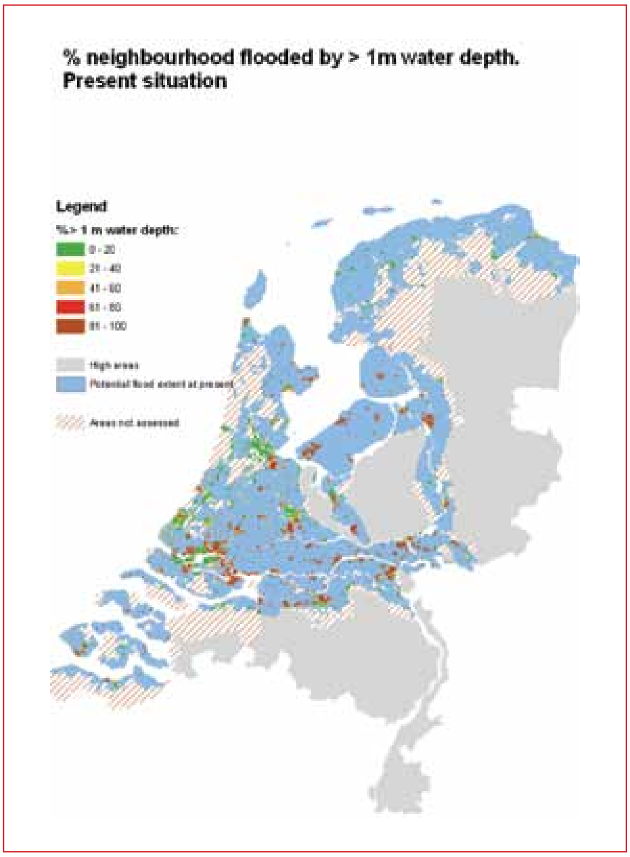
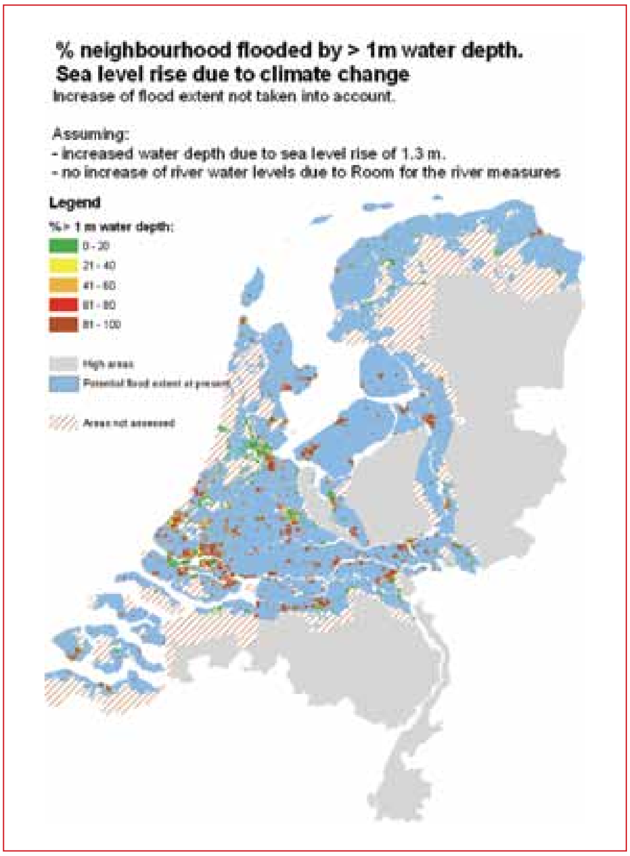


Figure 4.12 Ratio of centre areas built before 1940.

Climate change effects on exposure of urban area

The exposure of cities is likely to increase as a result of the climate change effects. Neighbourhoods could be affected by more severe floods due to the increase of water depth (figure 4.13). In addition, cities which at present are presumed to remain unflooded, become susceptible to flooding if flood extents increase. These effects are mainly expected for the cities in the coastal provinces and west of the IJssellake where large areas at present remain unflooded and overtopping of inner dikes could occur. An equal distribution of city functions is observed for the flood susceptible and flood free areas. It is therefore expected that the residential and industrial areas remain the most exposed to flooding. Post-war urban areas are more likely to be situated in flood susceptible areas, though it should be said that building in flood susceptible areas has always taken place throughout history.





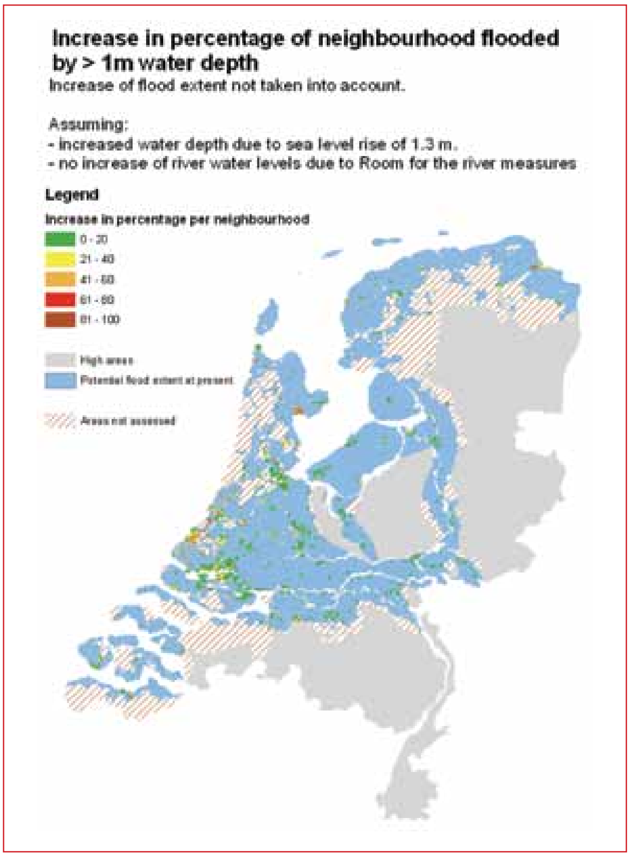


Figure 4.13 Percentage of neighbourhoods flooded by more than 1 metre water depth for the current situation, a situation with increased sea level rise and percentage increase (increase of flood extent not taken into account).

The effect of an increase of the water depth on the historical city centres appeared to be minimal. The historical city centres of Zwolle, Dordrecht, The Hague, Nijmegen and parts of Rotterdam are exposed to increased flooding depths. The city centres of Zwolle, Dordrecht, and, to a lesser extent, The Hague, are under current conditions already exposed to flooding.

4.2.3. Sensitivity to flooding of urban areas

Flooding can cause victims and result in structural and economic damage. The impact of a flood is determined by several flood characteristics. From previous studies (de Bruijn K. et al., 2008, Groot Zwaaftink M.E et al, 2007) the following indicators determining the impact of flooding have been formulated:

Indicator	Damages	Casualties
Water depth	•	•
Flow velocity	•	•
Rise of water rate		•
Distance to the breach. Determines the time between flooding of defence and the arrival of the water		•
Warning time		•
Distance to safe place		•
Accessibility of safe place		•
The last three point are often combined in an evacuation factor and mortality rate		•
Duration of flooding	•	

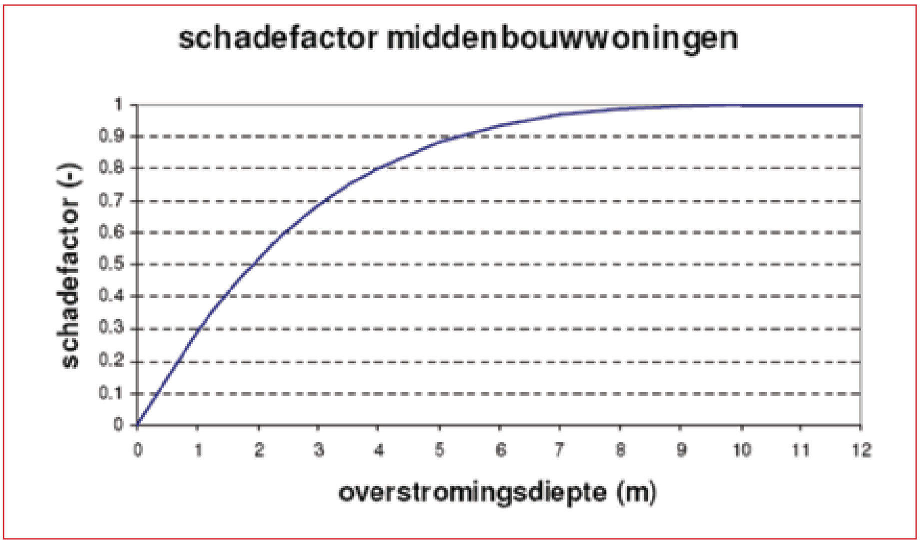
The expected water depth and flow velocity are important variables. They are used to evaluate the damages and casualties resulting from flooding. With the use of model simulations the maximum water depth per location for a flood event is determined. The flow velocity and water rise are of importance in the direct vicinity of the dike breach where they could reach dangerous values. For the remaining parts of The Netherlands these values are often low and thus negligible. For the determination of casualties, also the variables 'warning time' (predictability of a flood) and distance and accessibility to safe places are of importance. The prediction time for high river levels is 5 to 7 days, sufficient to implement measures and evacuate if needed. A storm along the coast can be predicted 24 to 48 hours ahead (with high uncertainty). For the determination of damages, the variable 'flood duration' is important. This is due to the fact that the water will accumulate in the lower areas and draining these areas could take up to weeks (for some areas even months). Information on flood duration is scarce, however, it can substantially influence the flood damage. Because of the lack of information, this indicator is rarely taken into account.

Flood damages in urban area

Expansion of the Dutch cities has been an ongoing process over the last 50 years. For certain areas, the impact of a flood will be larger than for others. In The Netherlands, damages are determined as a function of the water depth. Information on water depths is readily available.
When building in areas where large water depths are foreseen in case of flooding, an increase in damages can be expected.

The difference in damage for the current situation (water depth map) and a situation with an increased water depth was calculated using the HIS Damage and casualties module (HIS SSM module). This was done to gain an indicative impression of the increase of flood damage due to an increase of water depth.

A situation with an increased flood extent was not assessed. The HIS SSM calculates the damage per raster cell assuming the current land use situation. Economic and population growth are therefore not taken into account. Only the variable water depth was considered for the determination of the damages. Other variables e.g. flood duration and flow velocity which influence the damage, have not been taken into account. The relation between water depth and damages is illustrated in the HIS SSM graphs (Figure 4.14). In paragraph 4.2.2 we described that the functions 'Residential area' and 'industrial area' are the urban functions, which cover 75% of the urban area. Therefore, the graphs for businesses and average height buildings are pictured. The damage percentage increases as a function of water depth. A building partly flooded can be restored, but at a certain water level a building will be lost and maximum damage is reached.



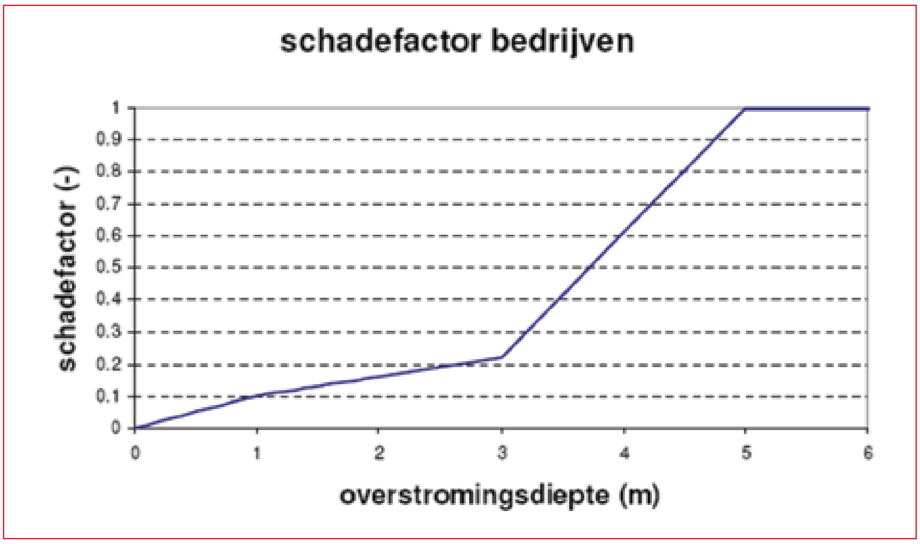


Figure 4.14 Relation between the water depth (horizontal axis) and damage factor (vertical axis) for average height buildings (upper graph) and businesses (lower graph) (Groot Zwaaftink M.E, 2007)

Figure 4.15 illustrates the resulting damage increase per 100x100 meter gridcel. Damage increases are mainly observed in the provinces of Zuid-Holland and Flevoland, the Northern coastal zone and west of the IJsselmeer. This is in accordance with the expected increase of water depth.

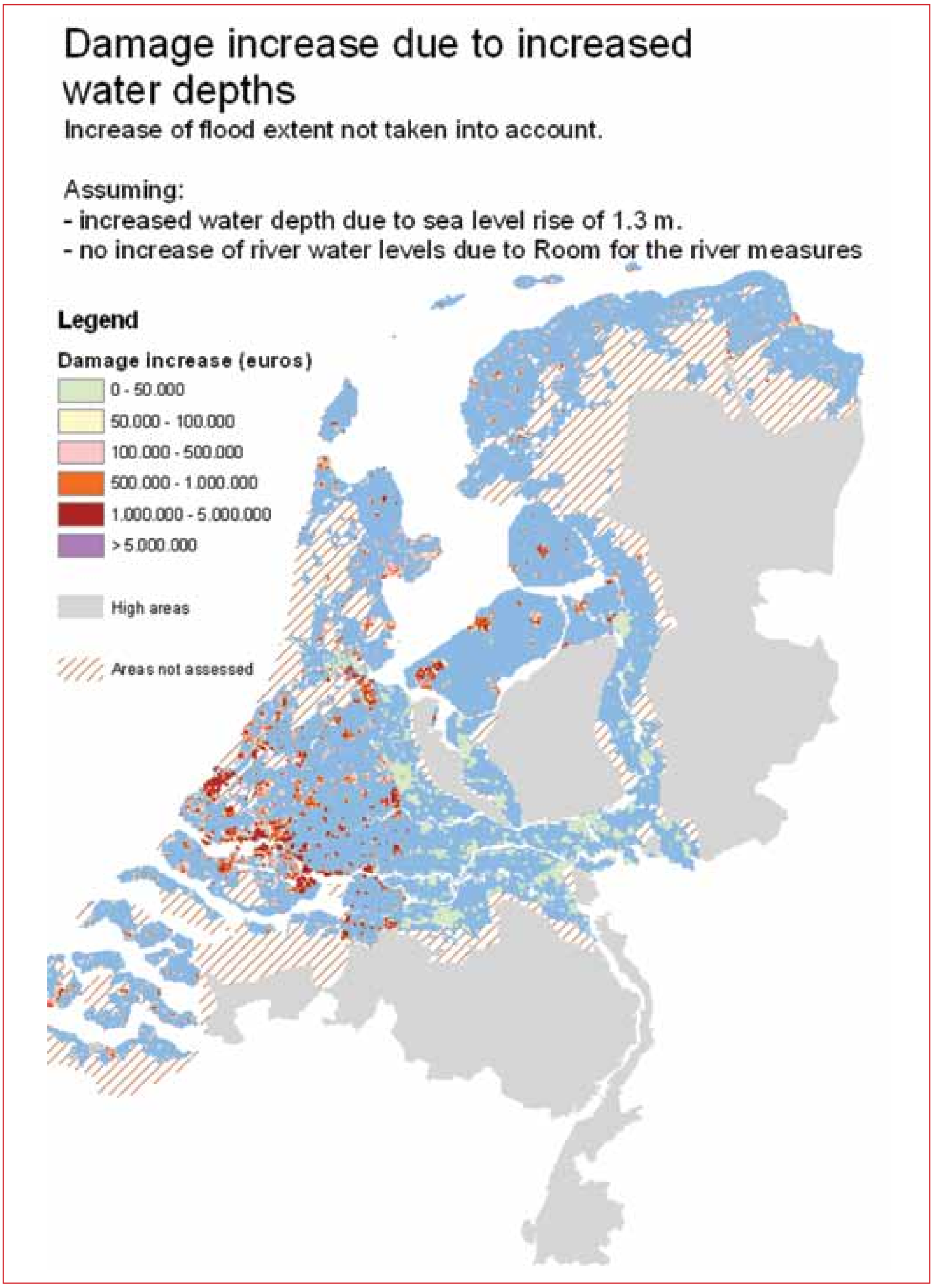


Figure 4.15 Damage increase due to climate change (sea level rise = 1.3 m)

Casualties urban area

The study *Mapping casualty risks in The Netherlands* (de Bruijn K. et al, 2008) evaluated the indicative individual and Group risk for The Netherlands at present. The risk calculation was based on the safety level, water depth, distance to the defence, evacuation factor and mortality rate. The results are shown in Figure 4.16 and Figure 4.17.

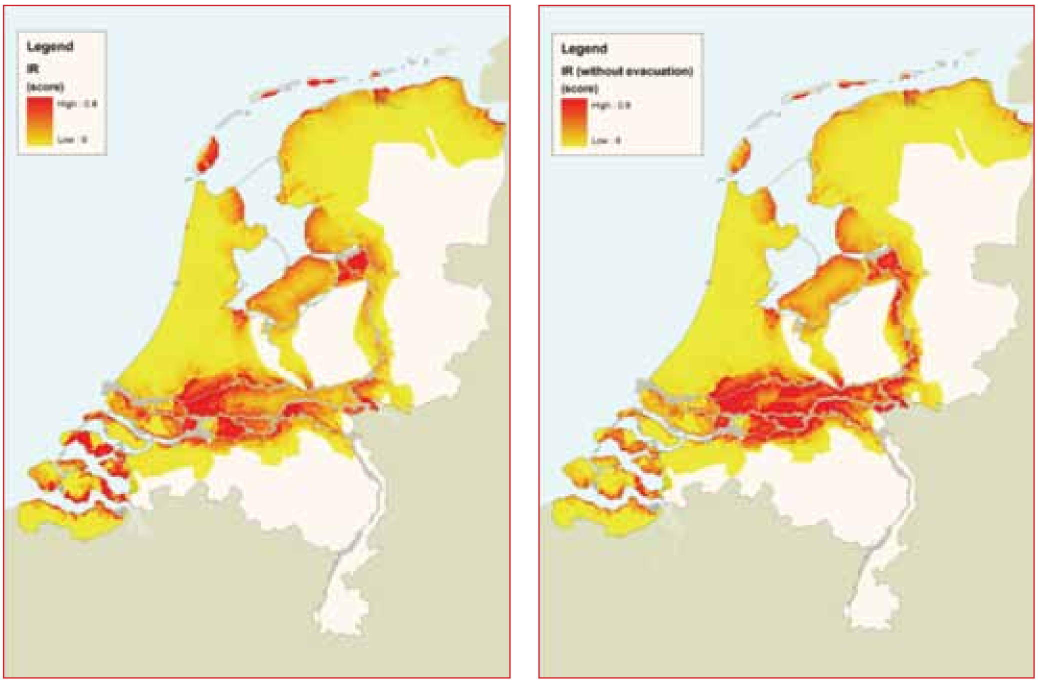


Figure 4.16 Locational risk with and without evacuation (de Bruijn K. et al, 2009)

The maps show that the potential risk of casualties is largest in areas threatened by river floods, especially where the water depths are high as well (e.g. the Alblasserwaard, the western part of the Betuwe and the Land van Maas en Waal, Rijnstrangen area, Mastenbroek). The islands in the north and south-east have a high risk of casualties due to the limited evacuation possibilities in combination with short warning time and large water depths (de Bruijn K. et al, 2009).

From the locational risk map, a group risk map was constructed to show the risk per city (on a relative scale). This map shows that the cities Dordrecht, Ridderkerk, Rotterdam-IJsselmonde, Spijkenisse, Den Bosch and Vlissingen have a higher Locational Risk than other cities (de Bruijn K. et al, 2008).

The individual and group risk is expected to increase for the coastal areas due to climate change. This is mainly due to the increased water depth and flood extent. Furhermore, these dike rings have an additional disadvantage. The short warning times for coastal storm surges and extent of the flooded area in combination with the large number of inhabitants within these areas, makes it impossible to evacuate everyone from these areas.

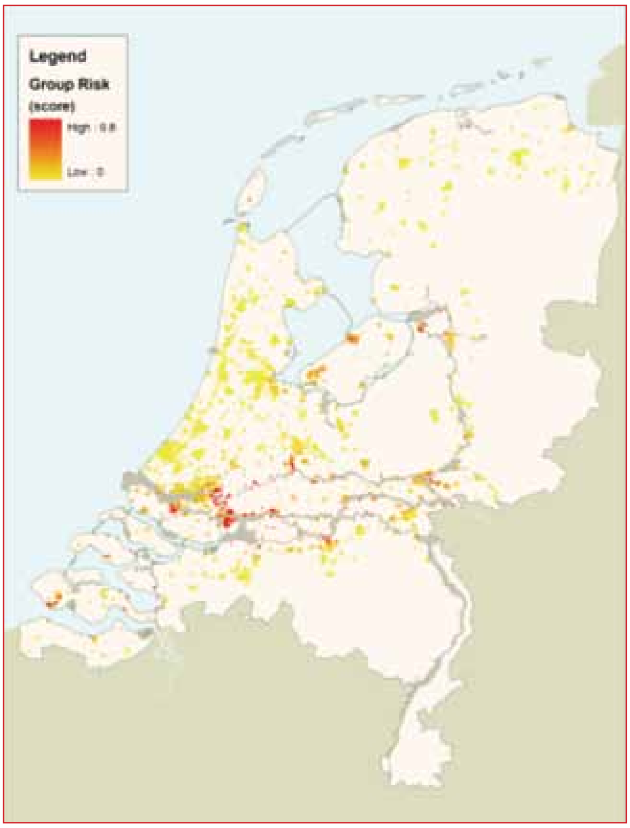


Figure 4.17 Indicative group risk (de Bruijn K. et al, 2009)

4.2.4. Intrinsic vulnerability of urban area to flooding

The intrinsic vulnerability is defined as the combined outcome of the hazard, exposure and sensitivity. The former three paragraphs studied the flood hazard, exposure and vulnerability of the Dutch urban areas.

Hazard

The flood safety standards for The Netherlands are very high. It can be assumed that the flood safety standards will be maintained and flood defences will be adapted to climate change effects. The probability of flooding will therefore not increase.

Exposure

If a flood were to occur, it is expected that water depth, flood extent and flood duration will increase due to climate change effects. At present, the cities located in the dike rings along the main rivers and IJsselmeer lake are more exposed to flooding. The exposure of cities will increase for the coastal areas; the Province of Zuid-Holland, The Province of Zeeland, the Northern coastal areas and west of the IJssel lake. This is due to an expected increased flood extent and water depths. Areas already highly exposed remain exposed. The functions 'Residential' and 'Industrial' cover 75% of the urban area and are therefore the functions most exposed to flooding. Post-war urban areas are more likely to be situated in flood susceptible areas, though it should be said that building in areas susceptible to flooding has always been the case. Historical city centres are mainly situated (80%) in flood free areas.

In future though, parts of historical centres which at present are expected to remain unflooded, could become exposed to flooding if more areas become prone to flooding.,

Sensitivity

Increasing water depths could lead to more damages for the provinces of Zuid-Holland and Flevoland, the Northern coastal zone and west of the IJssel lake. This does not take economic growth into account. At present, the potential number of casualties is largest in areas threatened by river floods, especially where the water depths could reach high levels. More casualties are expected for the larger coastal dike rings due to increasing water depths and flood extents.

Intrinsic vulnerability

When looking at the different aspects of intrinsic urban vulnerability to flooding, it turnes out that for The Netherlands the flooding probability is extremely low. The Dutch policy mainly focuses on flood prevention. The exposure and sensitivity to flooding (the impact of an actual flood) are therefore relatively high and rising, not only due to climate change effects, but also as a result of economic and population growth. It is not expected that the flooding probability will increase due to climate change, but the exposure and sensitivity to flooding are expected to increase. This is summarized in Figure 4.18

	Coastal and fluvial flooding from main rivers and regional waters	
	Current conditions	Climate change conditions
Hazard	‹‹	‹‹
Exposure	›	››
Sensitivity	›	››
Vulnerability	‹	‹›

Figure 4.18 Development of urban vulnerability to flooding due to climate change

The intrinsic vulnerability of urban areas to flooding is expected to increase in the provinces of Zuid-Holland, Zeeland and Flevoland and for the smaller towns in the Northern coastal area and west of the IJssel lake. This increase is caused by larger water depths and flood extents. The residential and industrial functions are the functions most vulnerable to climate change, although the economic value of the functions has not been considered yet. More casualties are expected for the larger coastal dike rings due to increasing water depths and flood extends.

4.2.5. Conclusion for water safety

- The Dutch policy aims to maintain the safety standards and thus to adapt the flood defences and river system to comply with the expected increase in extreme discharges and sea level rise. By maintaining the safety standards the probability of an actual flooding is not expected to increase;
- Due to climate change effects, water depth, extent of flooding and flood duration could increase;
- Little insight is available on the flood duration and the effects of climate change on an increase of flood extent;
- At present the cities located in the dike rings along the main rivers and IJsselmeer lake are more exposed to flooding;
- 'Residential' and 'Industrial' areas are the urban functions most exposed to flooding;
- Post-war urban areas are more likely to be situated in flood susceptible areas;
- Historical city centres are mainly situated (80%) in flood free areas;
- Due to an increased water depth, the cities located in the coastal areas; the Province of Zuid-Holland, The Province of Zeeland, the Northern coastal areas and west of the IJssel lake will be more exposed to flooding. Areas already highly exposed remain exposed;
- More areas could become prone to flooding in the future;
- Increasing water depths could lead to more damages for the provinces of Zuid-Holland and Flevoland, the Northern coastal zone and west of the IJssel lake. This does not take economic growth into account;
- At present, the potential number of casualties is largest in areas threatened by river floods, especially where the water depths could reach high levels;
- More casualties are expected for the larger coastal dike rings due to increasing water depths and flood extents;
- The intrinsic vulnerability to flooding of urban areas is expected to increase in the provinces of Zuid-Holland, Zeeland and Flevoland and for the smaller towns in the Northern coastal area and west of the IJssel lake. This development is caused by larger water depths and flood extents.

4.3. Water nuisance

An increase in average rainfall and in particular the occurrence of extreme rainfall events will lead to more water nuisance in urban areas. In this section a distinction is made between pluvial flooding and groundwater nuisance (high groundwater levels). These processes are described separately.

4.3.1. Effects of climate change (hazard)

The increase in the number of extreme rainfall events will result in more storm runoff and therefore in an increase of pluvial flooding. Both an increase in average rainfall as well as more extreme rainfall event will cause a notable rise of groundwater levels. Pluvial flooding and high groundwater levels both already cause water nuisance in urban areas. Climate change are likely to enhance the overall water nuisance in urban areas.

Compared to some of the tropical countries, the precipitation levels within The Netherlands are very moderate. Regional differences in extreme precipitation peaks are limited (Buishand et al, 2009) to 21% (KNMI, 2009) between the Rotterdam area and some of the areas within east and south-east. For yearly averages the ranges are somewhat bigger, resulting in a range of 46%. These differences are further narrowed down when looking at the densely populated areas. The Dutch 'Randstad' area containing the cities of Amsterdam, Rotterdam, The Hague and Utrecht show almost identical levels. Only in the Rotterdam area peak precipitation levels are somewhat higher. Peak and yearly average precipitation levels are shown in Figure 4.19.

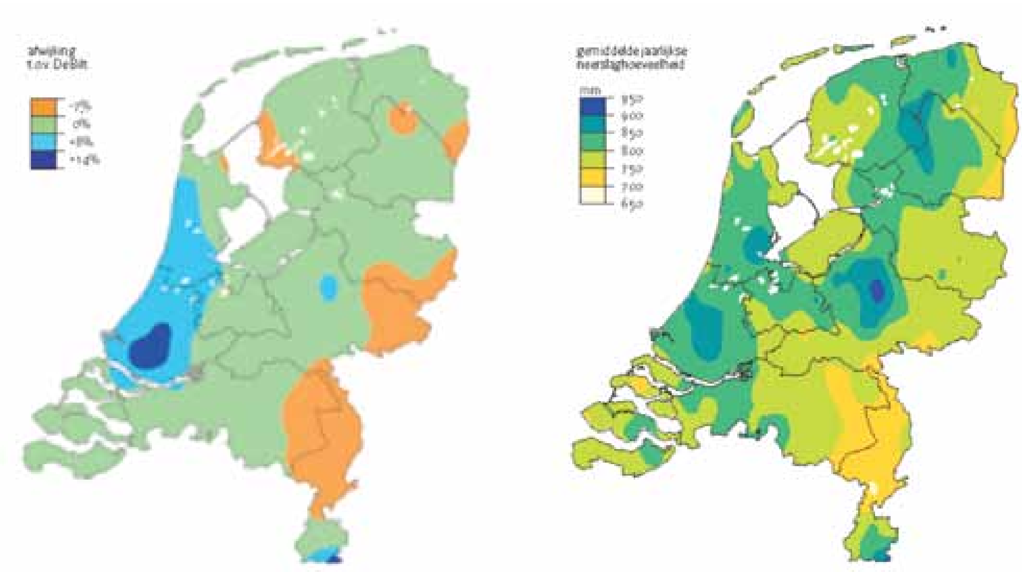


Figure 4.19 Peak precipitation deviations (left) and yearly averages (right). From Klimaatverandering in Nederland. Aanvullingen op de KNMI'06 klimaatscenario's (KNMI, 2009).

The G, G+, W and W+ scenarios (KNMI, 2009) applied in this study all result in increased precipitation levels. Currently, a 100 year rainfall event results in 43mm of rainfall per hour. For the W-scenario in which precipitation changes are most significant, this level rises to 53mm. The daily maxima in this scenario are expected to change from 79mm to 98mm.

While the distribution of yearly averages provide some indication of the distribution of frequent events, extreme rainfall events are local phenomena. Due to the modest area the Dutch administrative boundaries cover, they can be expected virtually anywhere. Although current efforts to downscale precipitation models are resulting in a larger differentiation level between areas, precise estimates on intensity levels for local rainstorms cannot be geographically determined. It is therefore prudent to use a uniform distribution of rainfall in which cities are exposed equally.

4.3.2. Exposure to surface runoff

The extent and intensity of expected pluvial flooding has first been determined using land-use and soil characteristics (Method 2, CNs). The method has been applied to all municipalities with 30.000 inhabitants or more, which covers all major urban areas in The Netherlands. The resulting surface runoff (the water that does not infiltrate into the soil layer) is an important indicator for pluvial flooding. A typical example of the results is presented in Figure 4.20 for the city of Rotterdam. The 54mm precipitation event in the example is associated to a 10 year rainfall event for the current probability distribution. What can be clearly perceived is the influence of impervious areas on runoff generation: especially in the harbour areas that consist of large continuous paved areas, surface runoff generation is high. Since Rotterdam is mainly constructed on top of a clay layer runoff levels, the infiltration capacity for storm water is limited. Therefore, runoff levels for pervious areas (e.g. parks) are considerable.

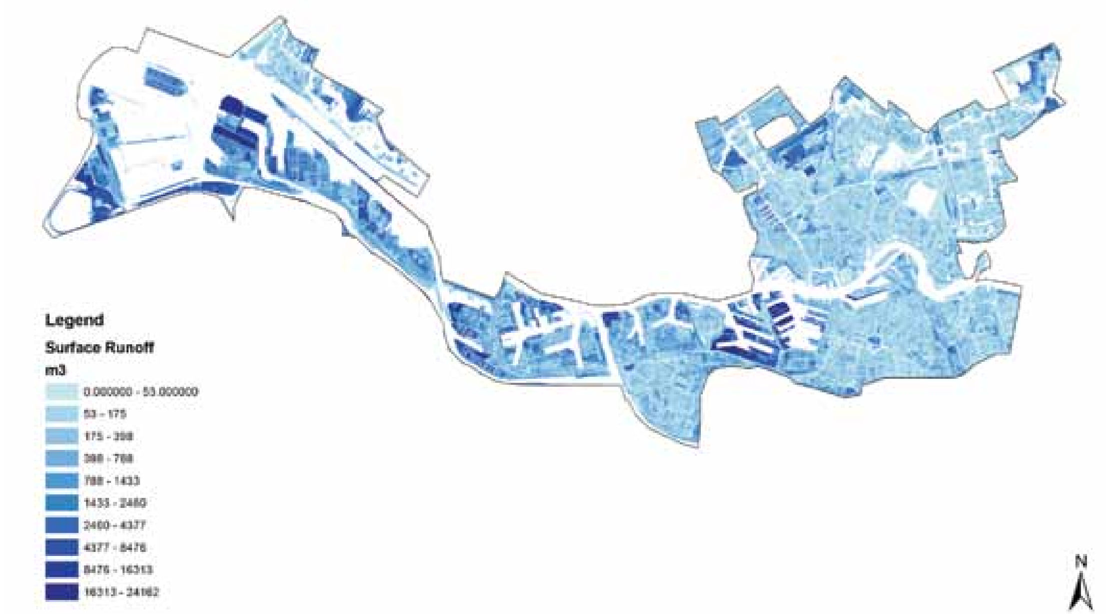


Figure 4.20 Predicted runoff distributions for a 54mm precipitation event for the Rotterdam urban extent.

The runoff distribution depicted for a local case as shown in Figure 4.20 suggests a strong correlation between industrial areas and surface runoff levels. Nevertheless, runoff levels in the urban centre of Rotterdam seem moderate. To investigate the relation between a variety of urban typologies and the observed runoff levels, a survey has been performed on the results for all urbanized areas within The Netherlands using the same level of detail as displayed in Figure 4.20. Classification of these areas, i.e. the urban typologies, is based on those developed by Ritsema van Eck et al (2009). This set consists of 19 different urban classes based on dominant functions and locations. The outcomes for an extreme event with a precipitation level of 89mm are shown in figure 4.21. This figure shows the distribution of the observed runoff coefficient for urban typologies using 40 bins. The runoff coefficient (RC) describes the percentage of precipitation that appears as surface runoff. Note that the distribution is only shown for the 6 most important urban typologies, i.e. those for which a strong correlation between typology and runoff level can be expected because of the anticipated level of imperviousness.

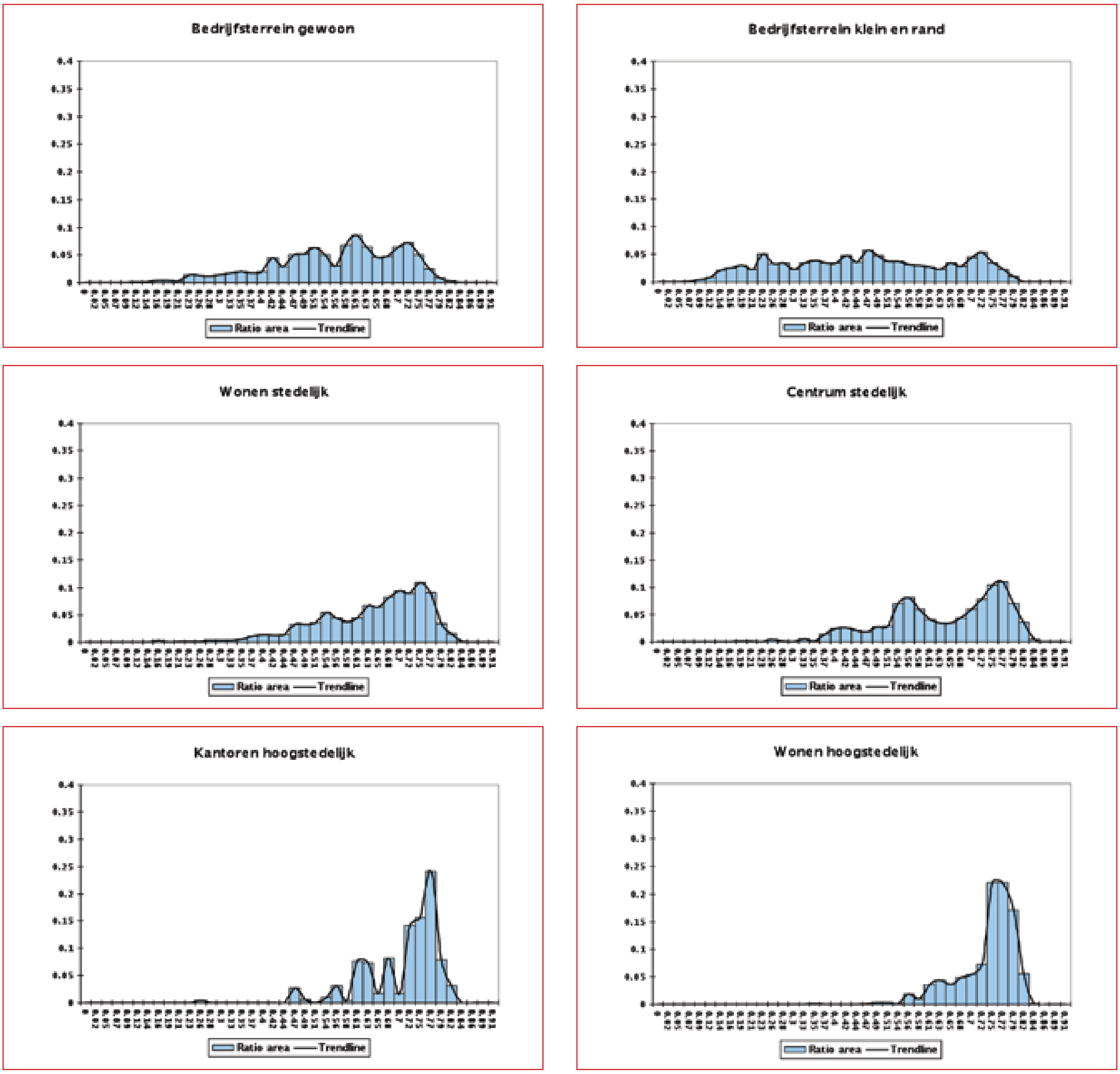


Figure 4.21 Runoff distribution for the complete range of urban typologies using a 88mm precipitation event

The first impression from the shown distributions is that these differ significantly. While for industrial areas the distribution is almost uniform, for other areas single or multiple peaks can be identified. When taking the runoff distributions for the complete range of 19 urban typologies, the perceived variations increase further; some urban typologies show strong correlations while for others the distribution is almost uniform. The most important conclusion from these observations is that urbanized areas are not necessarily prone to high surface runoff levels. Urbanized residential areas ('Wonen stedelijk') show a relatively flat distribution without strong peaks. Urban centres ('Centrum stedelijk') show two rather moderate peaks. Only within the downtown areas a trend can be observed towards high surface runoff levels. Furthermore, the observations made for industrial areas from the Rotterdam case-study cannot be generalized. The range in RCs for industrial areas ('Bedrijfsterrein gewoon' and 'Bedrijfsterrein klein en rand') is relatively large. Another more subtle observation is the appearance of 2 peaks in some of the distributions. RCs seem to 'organize' around two distinct intervals. This can be observed more clearly in the runoff distribution for downtown areas, depicted in Figure 4.22.

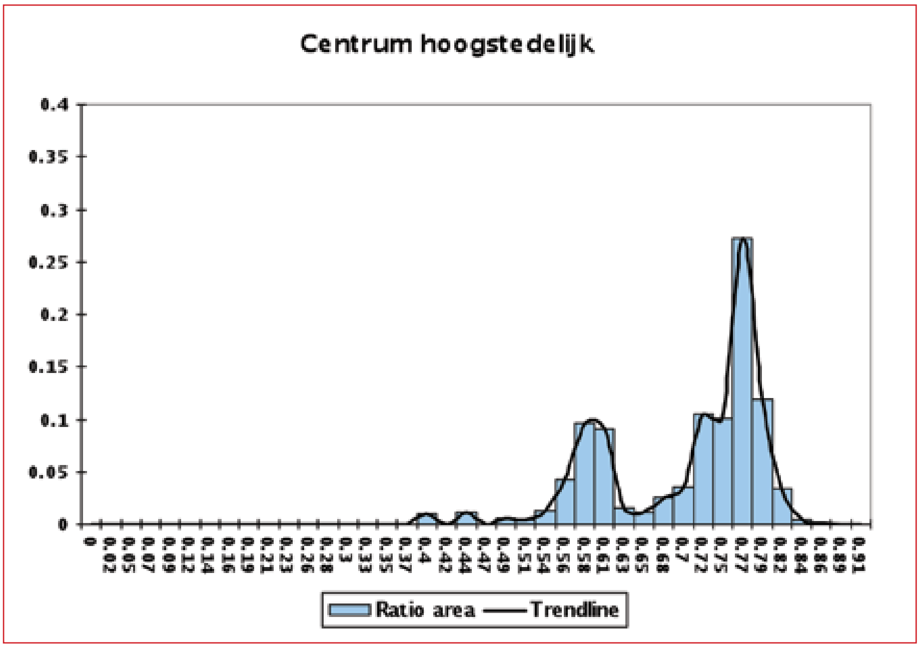


Figure 4.22 Runoff distribution for dense urban centres using a 89mm precipitation event

In absolute terms, the observed RCs for the downtown areas are moderate. Typically these range between 0.7 and 0.95. Analysis of the distributions shows that the Dutch downtown areas fall within the lower end of this range. Almost all urban types for the downtown areas show peaks around a RC of 0.77. The observed distribution leads to a following set of conclusions:

- With the exception of downtown areas, there is no significant relation between urban typology and runoff generation;
- Some urban typologies show multiple peaks around RCs;
- Industrial areas are not necessarily generating high runoff levels.

The absence of a clear relation between urban typologies and observed RCs can be explained from an apparent differentiation within the different urban areas in Dutch cities. Urban plans between cities differ leading up to different spatial distributions of pervious and impervious areas; e.g., green areas might be almost absent in some cities while having a considerable affect in others. Especially for industrial areas this is important since the general perception that these areas are prone to pluvial flooding is not supported by these observations. The level of urban differentiation seems to be less significant for urban typologies in central zones. Apparently, urban centres in The Netherlands are relatively dense and lack significant amounts of impervious areas (parks). Finally, the appearance of multiple peaks might be caused by the different infiltration rates related to the soil groups on which the cities are distributed.

To examine this hypothesis, the geographical distribution of the runoff levels has been calculated for urban areas located on two of the main soil groups: cities located on clay and sand layers. Especially for higher levels of precipitation, compared to sand, the infiltration capacity of clay is limited. The assumption therefore is that cities located on sand (mostly located in the East) show a different runoff levels than those located on clay (Western part). The results are shown in Figure 4.23.

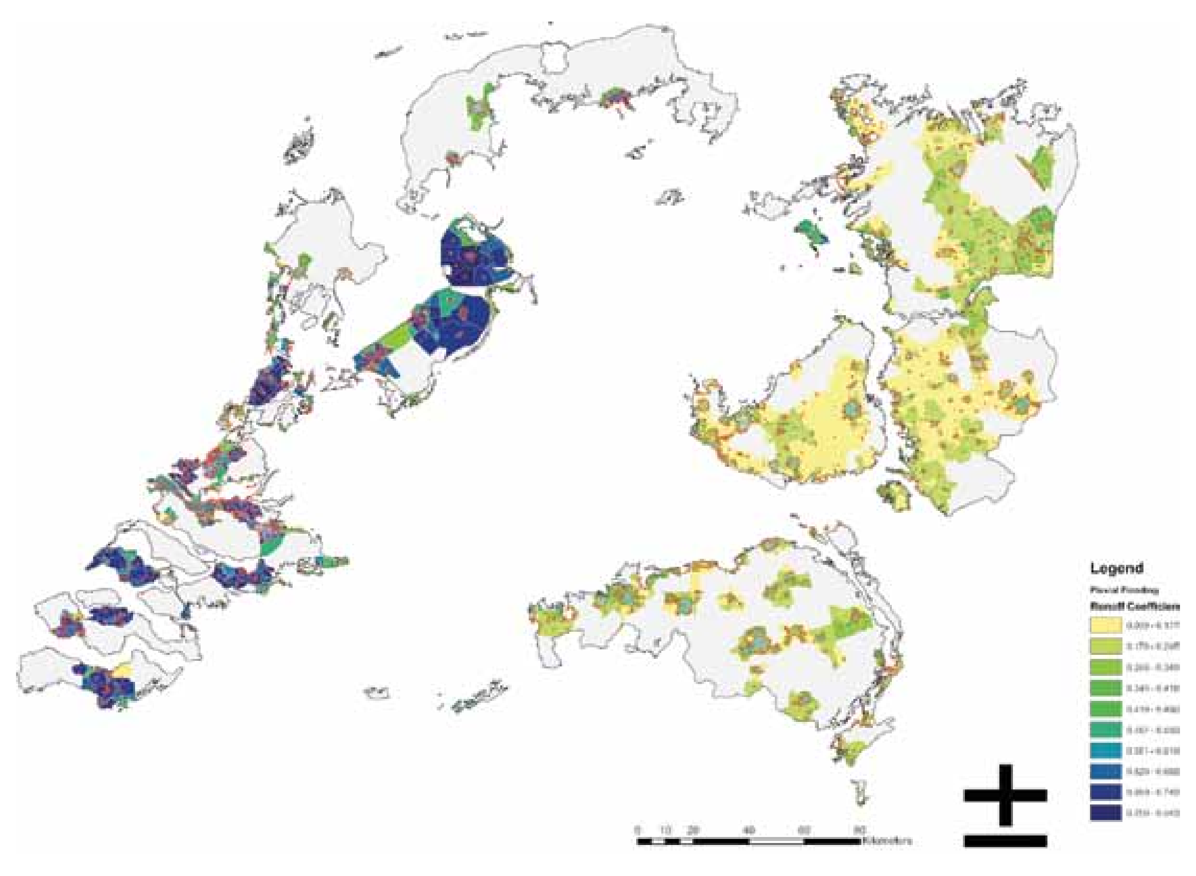


Figure 4.23 Spatial distribution of runoff for 2 main categories of soil types: clay (left) and sand (right)

What can be clearly perceived from Figure 4.23 is that soil differences are indeed a prime factor in runoff generation. The runoff levels for areas in the West, which are located on clay-based soils, are substantially higher than those for the East of The Netherlands. This difference can run up to about 35%. Note that the applied method only uses the top soil characteristics and no groundwater modelling is used during calculations.

The question now remains if the results are generally applicable or that a bias has been created because of the relatively extreme event that has been used for calculations. Note that an 88mm rainfall event is corresponding to a 100-year period using a moderate climate change scenario. To get a broader impression the calculations as described above have been performed for the following range of precipitation events:

- 33mm: corresponding to a 1 day aggregate precipitation level with a 1 year return period using the current probability distribution
- 54mm: as above but for a 10-year return period
- 79mm: as above but for a 100-year return period
- 88mm: as above but for a 100-year return period using the G or W+ scenario for climate change (KNMI, 2009).

The aggregate results are depicted in fig. 4.24 while calculations for downtown areas ('Centrum Hoogstedelijk') and suburbs ('Wonen Laagstedelijk) are depicted in Figure 4.25 and Figure 4.26.

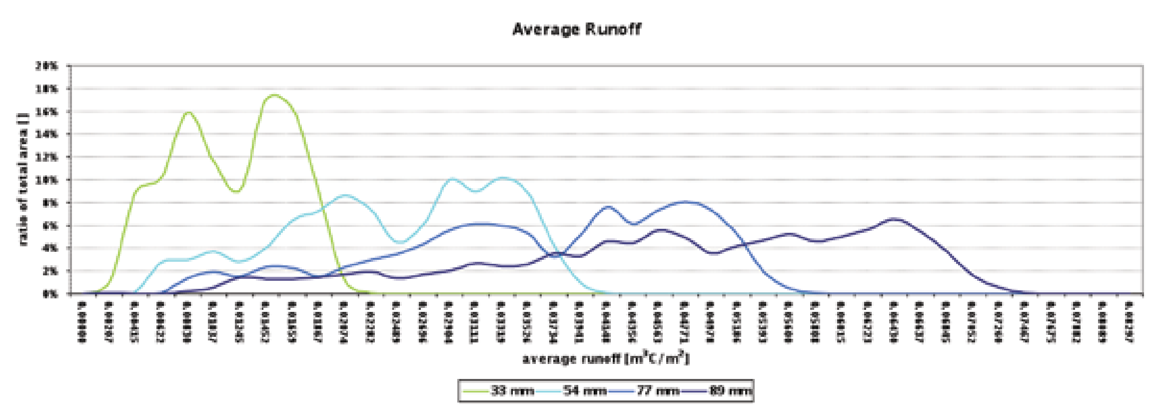


Figure 4.24 Average runoff distributions for all cities

For frequent precipitation events with a return period of 1 year, the correlation between land use and resulting runoff levels is relatively high. Additionally, the two peaks resulting from different soil conditions can be perceived clearly. For the complete urban extent, the observed runoff levels are relatively modest (around 0.08 and 0.015 m^3/m^2) which result in RCs of 24% and 45%. However, when precipitation levels are increased, the shape of distribution seems to ‘flatten out’ indicating a loss of correlation. In other words, runoff generation seems relatively predictable for moderate rainfall events while during extreme events, runoff generation is determined by local conditions. This is an important observation since the assumption might be that cities perform equally during extreme conditions because the precipitation levels are much more dominant. Yet, local differences in the urban layout (e.g. vegetation structures) are dominating the behaviour during extreme conditions.

Although the variability within the distribution increases, the observations show a linear relation between rainfall intensity and the observed mean runoff levels ΔQ_m:

$$\Delta Q_m = 0.629I - 9.7119 \quad (1)$$

, where I is the rainfall intensity in mm. Eq. 1 has a standard error of 0.4496 which results in a correlation coefficient of 0.99.

One of the questions that remain is if this shift towards a uniform distribution for higher precipitation levels occurs for all typologies. Therefore, the observed runoff distributions for the different rainfall intensities have been analyzed for two characteristic urban typologies: the downtown areas and the suburbs. These are shown in Figure 4.25 and Figure 4.26.

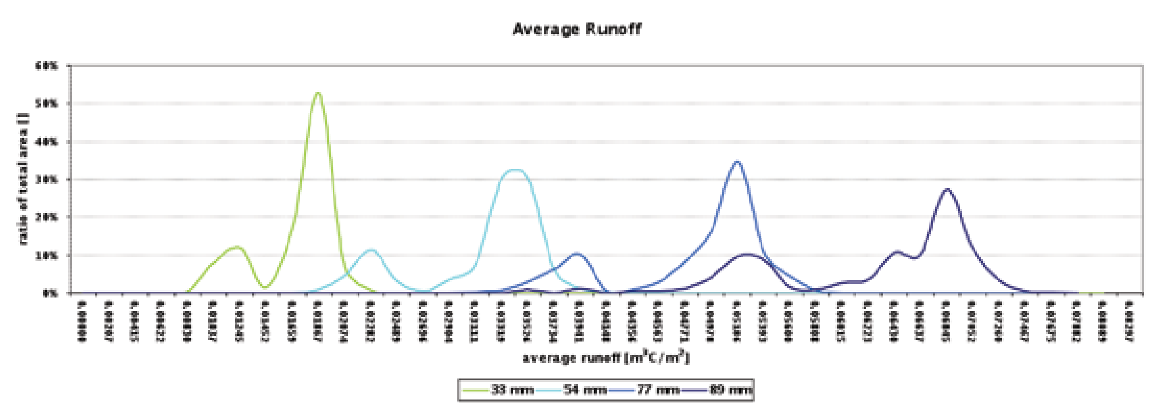


Figure 4.25 Average runoff distributions for downtown areas

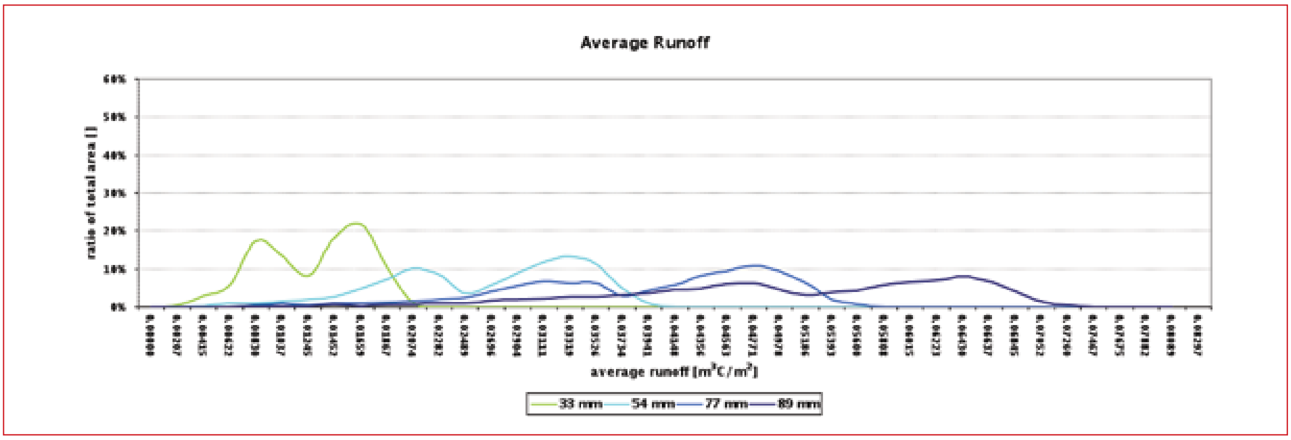


Figure 4.26 Average runoff distributions for suburban areas

Analysis of Figure 4.25 **and** Figure 4.26.shows different behaviour for the two types. While the behaviour for suburbs ('Wonen Laagstedelijk) is similar to that for the complete urban extent (figure 4.24), the behaviour of the downtown areas ('Centrum Hoogstedelijk') shows different characteristics. Here the observed peaks shift to the right, indicating substantially higher runoff levels for all downtown areas in The Netherlands. Although the level of the peaks is declining, the main characteristics change only marginally. This observation is important since it seems to prove that runoff (and possibly urban flooding) will increase significantly in Dutch city centres. For low density housing areas on the other hand, the chance of flooding differs per location.

Finally, these outcomes are validated by examining the geographic distribution. The results are depicted in figure 4.27, in which the runoff intensities for a 33mm, 54mm, 79 and 88mm event are shown. Note that the results are shown as average values per municipality. Individual differences between urban typologies as observed earlier are too small to display.

As can be perceived, runoff generation for the 1 year event (33mm) shows similar runoff levels all over The Netherlands, which confirms earlier observations. For higher precipitation levels (e.g. 88 mm) the distribution appears to be divided into soil groups (as observed earlier). Yet, quantitative analysis does not confirm this for all urban typologies.

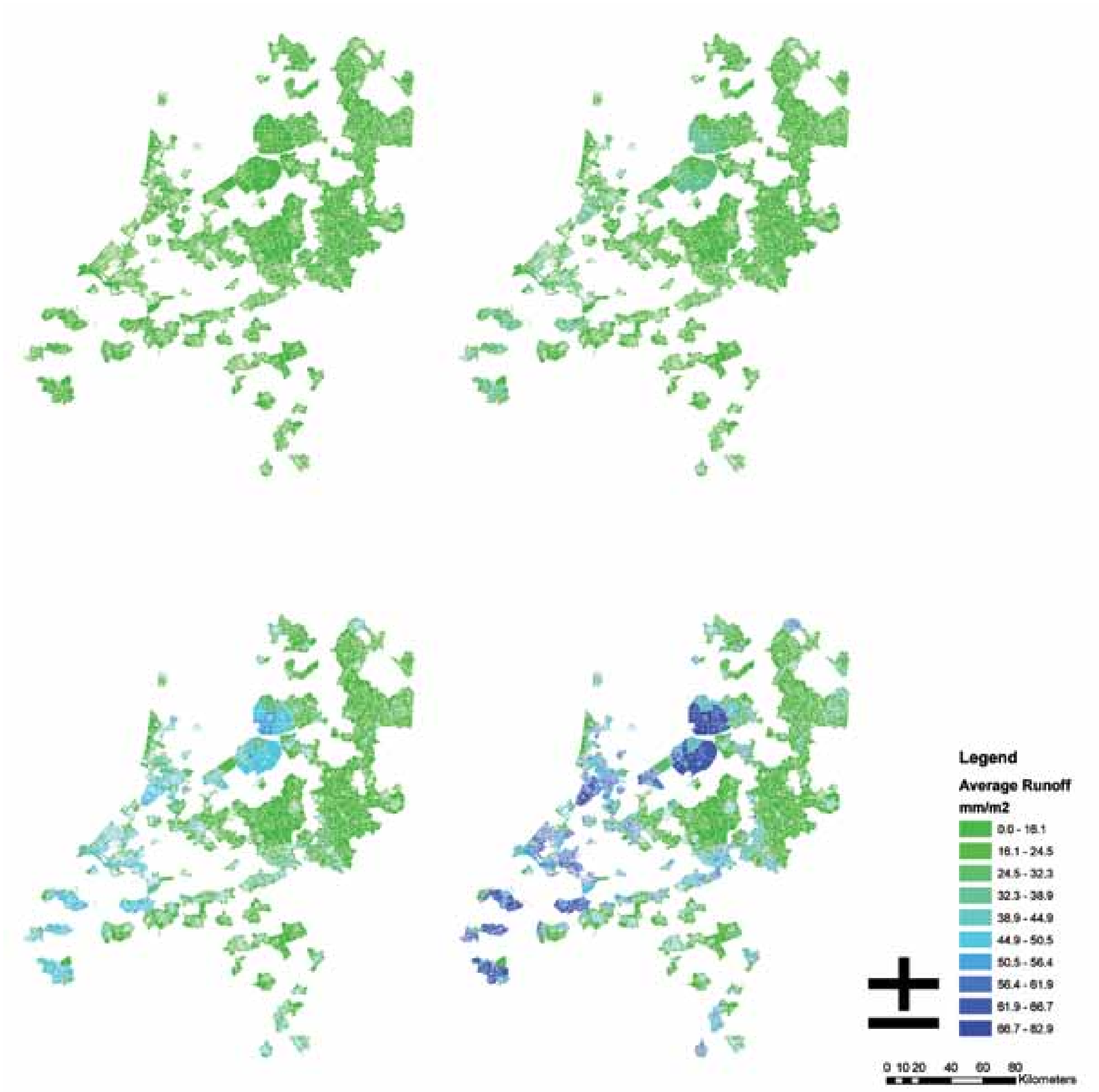


Figure 4.27 Spatial distribution of runoff on neighbourhood level for a 33mm (top left), 54mm (top right), 79mm (bottom left) and 88m rainfall event (bottom right)

Graduality and convexity

To gain further insight in the behaviour of the urban typologies for the applied range of rainfall intensities, the graduality has been calculated. The results are depicted in Figure 4.28 and include the same urban typologies as shown in Figure 4.21.

What can be observed is that for all typologies the left tail of the 95% confidence interval starts around 0.5 and extends to about 0.75. The interpretation of this value is somewhat problematic: while it is clear that a gradual response would result in a value close to 1 and a single stepwise progression of runoff in a graduality of 0, ranges between 0.5 and 0.75 perform can be a result of a combination of values (see Appendix A Methodology). Especially the values close to 0.5 could be a source of concern; generally in this case 2 out of 4 rainfall intensities are responsible for a disproportional contribution to the runoff levels. Especially down-

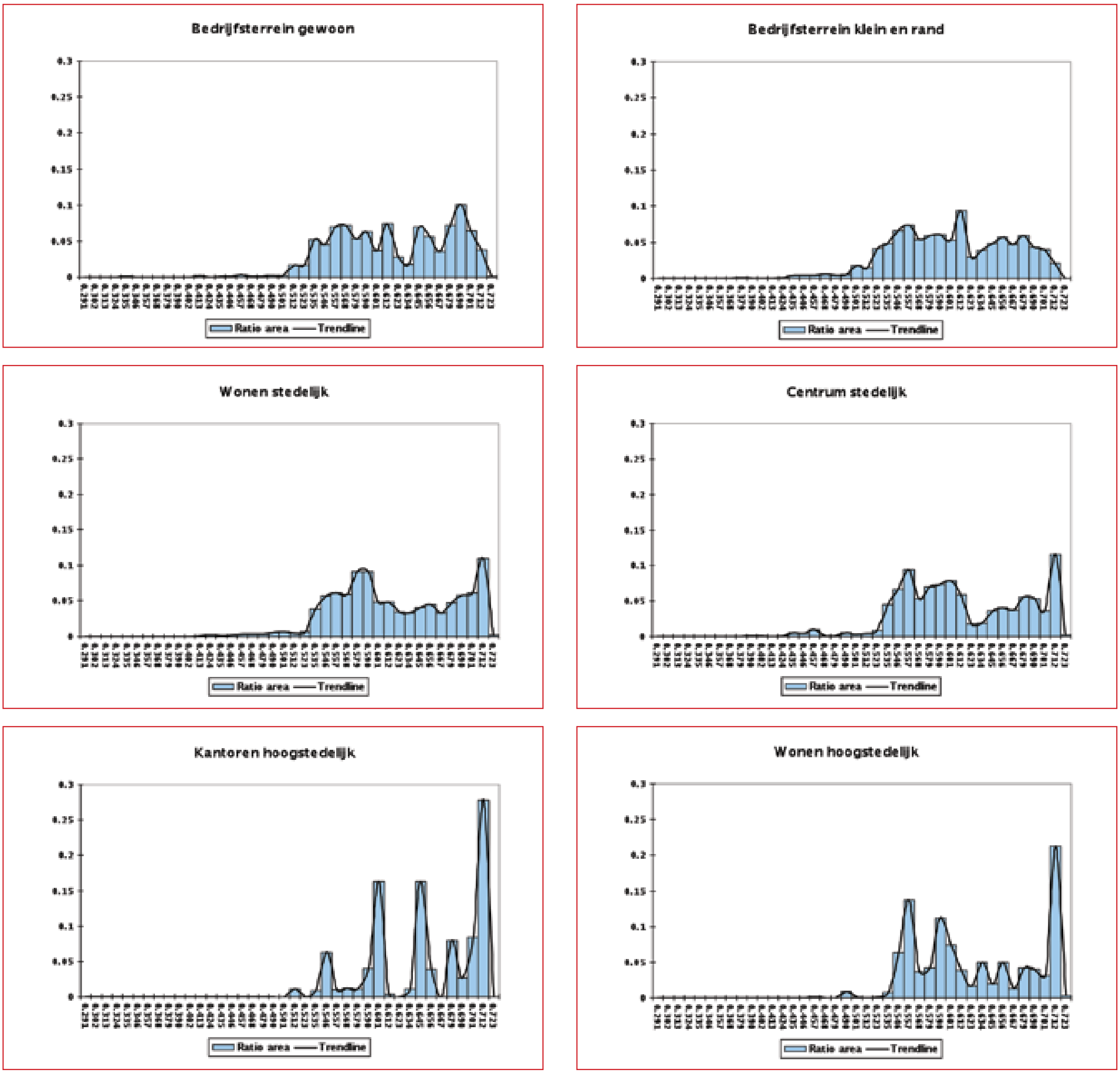


Figure 4.28 Graduality distributions for the complete range of urban typologies

town areas ('Centrum Hoogstedelijk') seem to suffer from low graduality levels (see Figure 4.29). To a lesser extend many of the other typologies show similar results. Finally, for now urban typologies the graduality reaches a value of 1.0. This suggest that Dutch cities in which the surface run-off shows a linear relation to the rainfall intensity doesn't exist.

This observation provides further evidence that increasing precipitation levels resulting from climate change do not simply lead to similar trend changes in surface runoff levels.

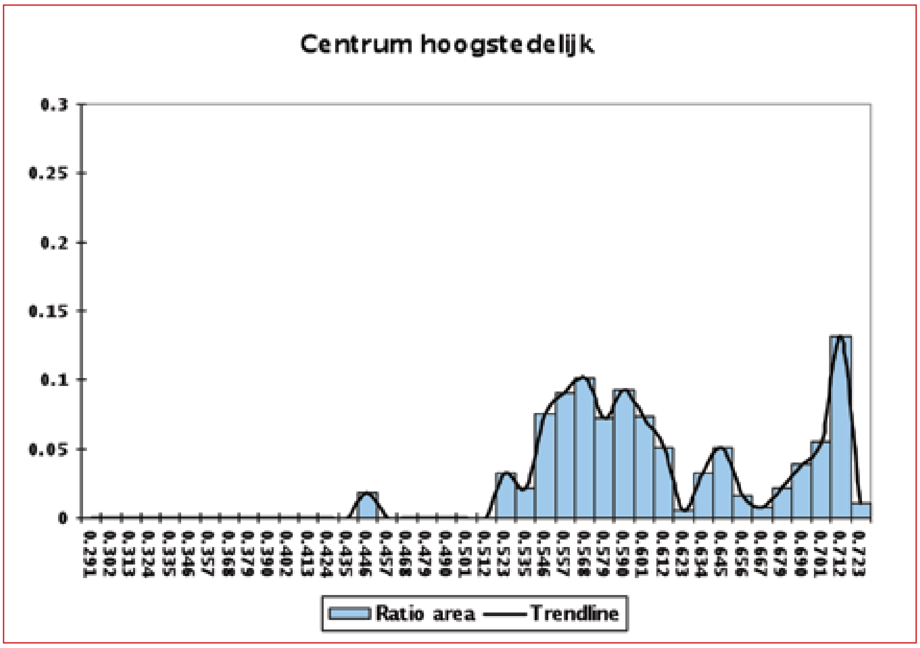


Figure 4.29 Graduality distributions for downtown areas

Finally, the exposure function has been tested for convexity. Here the values are much closer: 52.5% of the areas show a convex exposure progression function while for 47.5% of the areas this function is concave.

Table 4.3 Graduality and convexity: Descriptive Statistics

Min	0.291
Max	0.734
Mean	0.606
Std. Dev.	0.062
95% Conf. Interval	[0.479-0.734]
Convex	52.5%
Concave	47.5%

Exposure to surface runoff for individual cities

It is difficult if not impossible to acquire insights in flood sensitivity from surface runoff calculations; these merely indicate the possibilities for natural drainage through ground infiltration of rainwater. That does on the other hand prove to be a prime indicator for urban flooding. While the relation between urban typologies and surface runoff have been described extensively in the previous paragraphs, it might be useful to investigate the RCs for some of the major Dutch cities. Note that these only provide general characteristics; local conditions within the cities might differ from place to place. The results for a 1 year (33mm/24hours) and 100 year (54mm/24hours) rainfall event in the current probability distribution are shown in Figure 4.30 (left). Since on average the Dutch storm water drainage system in cities can absorb about 20mm of water, the RCs are effectively lower. These resulting RCs are shown in Figure 4.30 (right).

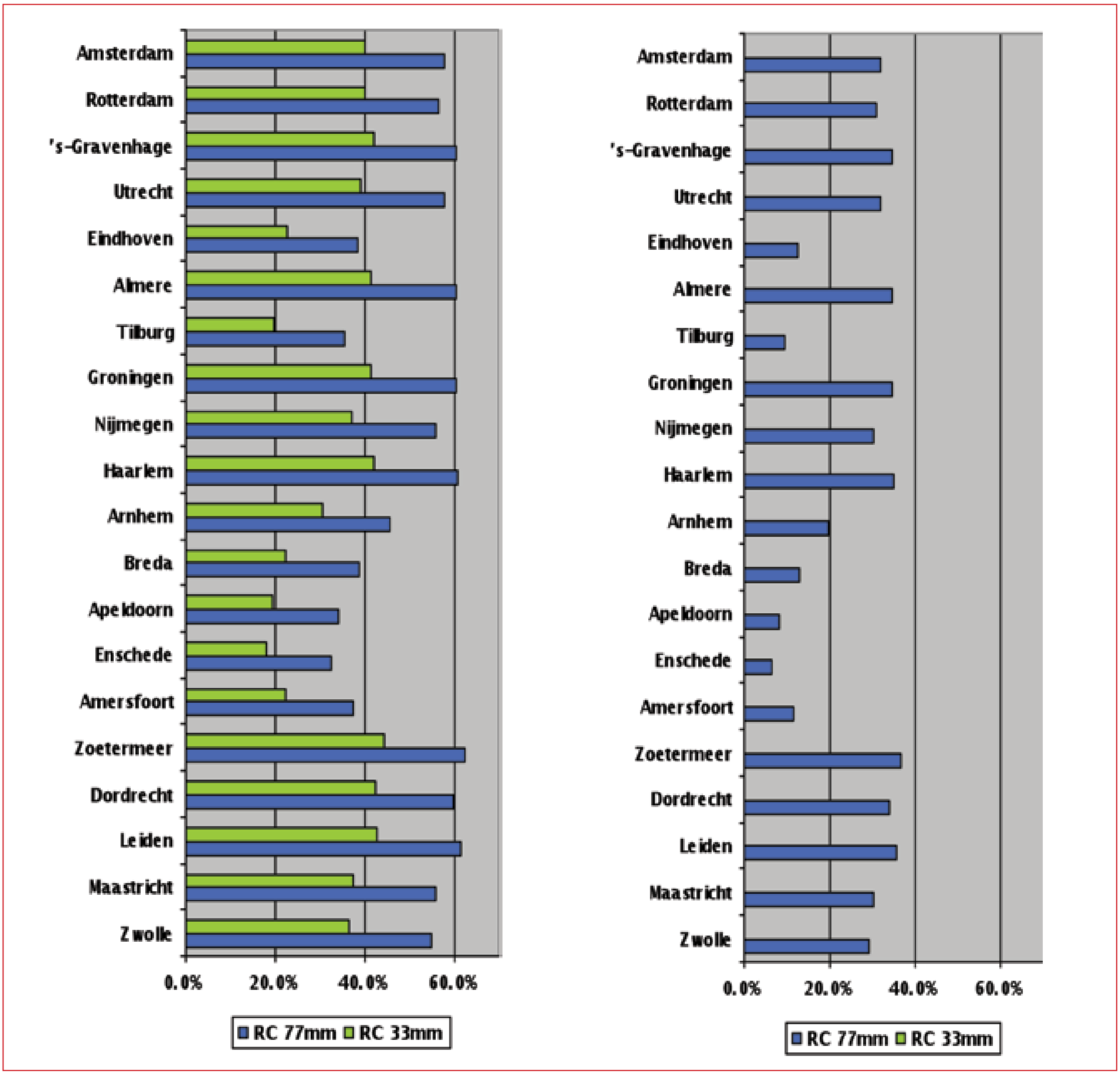


Figure 4.30 Average runoff coefficients for the top20 biggest cities with (left) and without (right) the influence of storm water drainage

As identified earlier, the influence of soil conditions on the runoff behaviour can be clearly observed in figure 4.30 left. All cities showing lower RCs (e.g. Tilburg, Apeldoorn, Enschede) are located on sand layers, while those with higher RCs (Amsterdam, The Hague, Zoetermeer) are located on clay soils. The absolute influence of higher precipitation levels doesn't seem to differ substantially between cities. Adding 44mm on top of the 33mm rainfall event increases the RCs with an additional 20%. Relatively though, cities located on sand layers suffer more from the 100 year event. The relative increase ranges between 68.2% for Amersfoort to 80.0% for Tilburg. For clay based cities this range is much smaller: 41.0% for Rotterdam to 51.2% for Zwolle. The conclusion from this is that the baseline level for the cities located on clay is much higher than the one for cities located on sand. Consequently, the saturation of soil associated with a 100 year rainfall event has much more effect for the sand based cities.

The effect of the storm water drainage system is clearly observable. The resulting surface runoff for the 1 year event (33 mm/24 hours) has completely disappeared. For the 100 year event, the reduction varies substantially. For cities located on clay the absolute difference ranges between 4.8% for Zoetermeer to 30.1% in Arnhem. For cities located on sand this ranges between 56.1% in Amersfoort and 71.7% in Enschede. In other words, the influence of storm water drainage networks generates a substantial reduction in surface runoff for extreme events on especially sand based cities. Note that this reduction might be less because of anthropogenic factors; pumps, pipes and other components might malfunction and therefore reduce the effective capacity. Additionally, the reduction depends on the individual layout of the drainage network within each city; the storage capacity differ between locations.

4.3.3. From surface runoff to pluvial flooding

Although surface runoff and the occurrence of pluvial flooding are strongly related, the outcomes produced by the Cn-method do not provide information about the expected flood stages (see Appendix A). Neither do they show where flooding is to be expected on a local scale. To gain more insight in the actual exposure to flooding, the flow accumulation has been determined for the complete Dutch urban extent. To gain some insights in the models behaviour, the spatial distribution of results is presented on a local level of detail for the city of Delft in Figure 4.31. Note that the occurrence of flooding in this model strictly depends on the location of local depressions (sinks).

What can be immediately perceived, is that the locations where flooding occur seems almost randomly spread. A large amount of micro-basins indicates the appearance of many local depressions in the city.
Since Dutch cities are relatively flat, local depressions occur frequently but result only in moderate flood stages. Especially in the dense urban centre, these occur often next to buildings, which might lead to flooded basements and other problems.

Using the different rainfall events, the spread of urban flooding has been investigated for the complete Dutch urban extent. For this calculation, the buildings have been removed; the analysis only covers public space and infrastructure. Because of the relative flatness, the distribution of flow accumulation and the associated flood stages should show a strong peak in the lower end; many local depressions are expected to cause small puddles with minimal depths. The outcomes are shown in Figure 4.32.

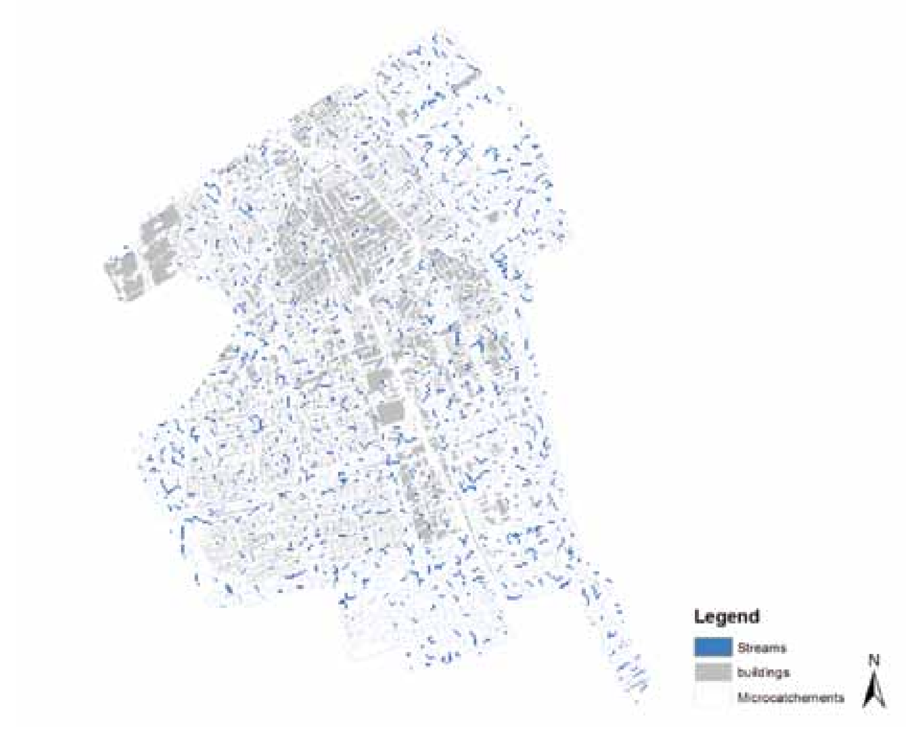


Figure 4.31 Flow accumulations for Delft

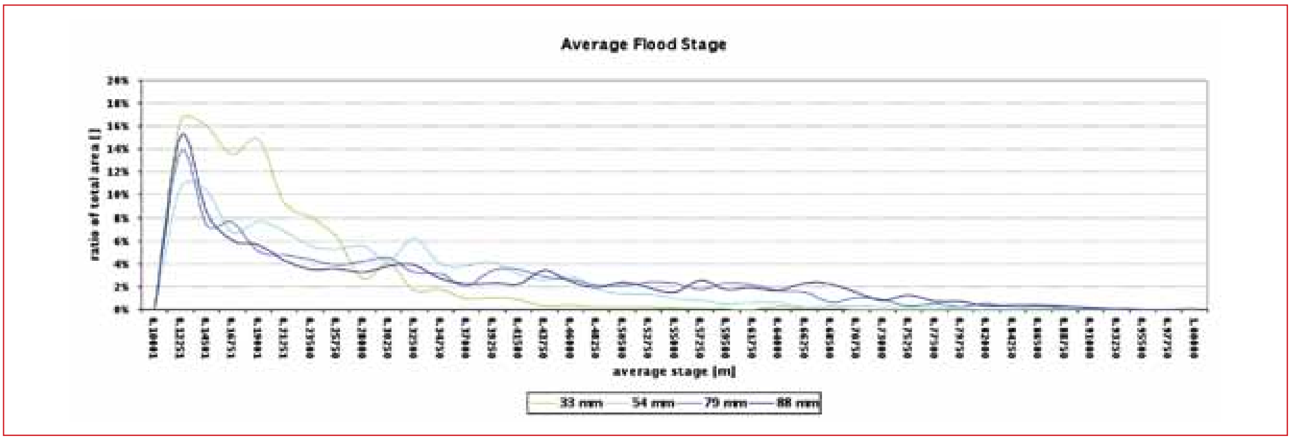


Figure 4.32 Distributions of expected flood stages

The results in Figure 4.32 show that for the 4 applied rainfall events, the majority of expected flood stages lie below 20cm. This peak is stronger for the events using 79 and 88mm. For the two lower intensities (33mm and 54mm) the peak is somewhat distorted. This can be explained by looking at the complete distributions. Since especially for the 33mm event 95% of the expected flood stages are less than 37cm, the results for the lower end of the graph (left) are distorted; the majority of flood stages are within the lower range. For the 79mm and 88mm event, the graphs 'even out' since the range of observed flood stages is much larger. For the extreme 88mm event, the range for the 95% confidence interval is much larger. Here the limit is reached at 73cm. The conclusion of these observations is that for stronger rainfall events, the expected flood stages can be divided into two categories:

- 30% of the flood stages are below 16cm;
- The rest of the distribution is rather uniform and therefore unpredictable.

The occurrence of flood stages beyond 50cm is alarming. For the 79mm event, this comprises about 17% of the total urban extent, while for the 88mm this has risen to about 20%.

Note that the influence of storm water drainage networks is not taken into account. Since flood accumulation depends on local depressions, the assumption of a uniformly distributed 20mm reduction resulting from storm water drainage capacity would not apply. Since flow accumulation depends on the size of the micro-watersheds, smaller watersheds would benefit relatively more from this reduction. This would create a bias in the outcomes. In general, however, it can be concluded that the larger the distance is towards open water (in which storm water drainage can discharge during extreme rainfall), the more exposed an area is to pluvial flooding.

4.3.4. Sensitivity and intrinsic vulnerability to pluvial flooding

The calculation of flood stages and their respective locations does not indicate if the expected flooding becomes actually problematic; temporary flooding of parks or vegetation might be perceived as a nuisance, but might not actually result in damages. Similarly, the flooding of small access roads does not disrupt major traffic flows vital for local or regional transportation. Even if flooding takes place adjacent to buildings, these might suffer only marginally from lower flood stages. In other words, sensitivity to flooding depends largely on local conditions.

While for the estimation of direct damages various tools are available, these methods do not do justice to the level of detail applied in this study. Available stage-damage curves in which expected damages are related to different levels of flood stages, are available only for broad scale levels in which specific urban typologies (e.g. downtown vs outskirts) is not taken into account (e.g. Veerbeek, 2009). The obtained results become even more questionable in relation to the expected flood stages. Contrary to those occurring from fluvial (river floods) or coastal flooding, these are relatively low. Especially for frequent events in which the majority of expected flood stages resulting from rainfall with in the range of a few decimetres, local perturbations are likely to distort the outcomes dramatically. Therefore, the chosen metrics to estimate the intrinsic vulnerability is the ratio of affected buildings and infrastructure. The resulting outcomes measure these ratios based on the total area covered by the housing and infrastructure extent of within cities. The results are displayed in Figure 4.33 using a 10 year event (54mm) and a 100 year event (77mm) for the current probability distribution.

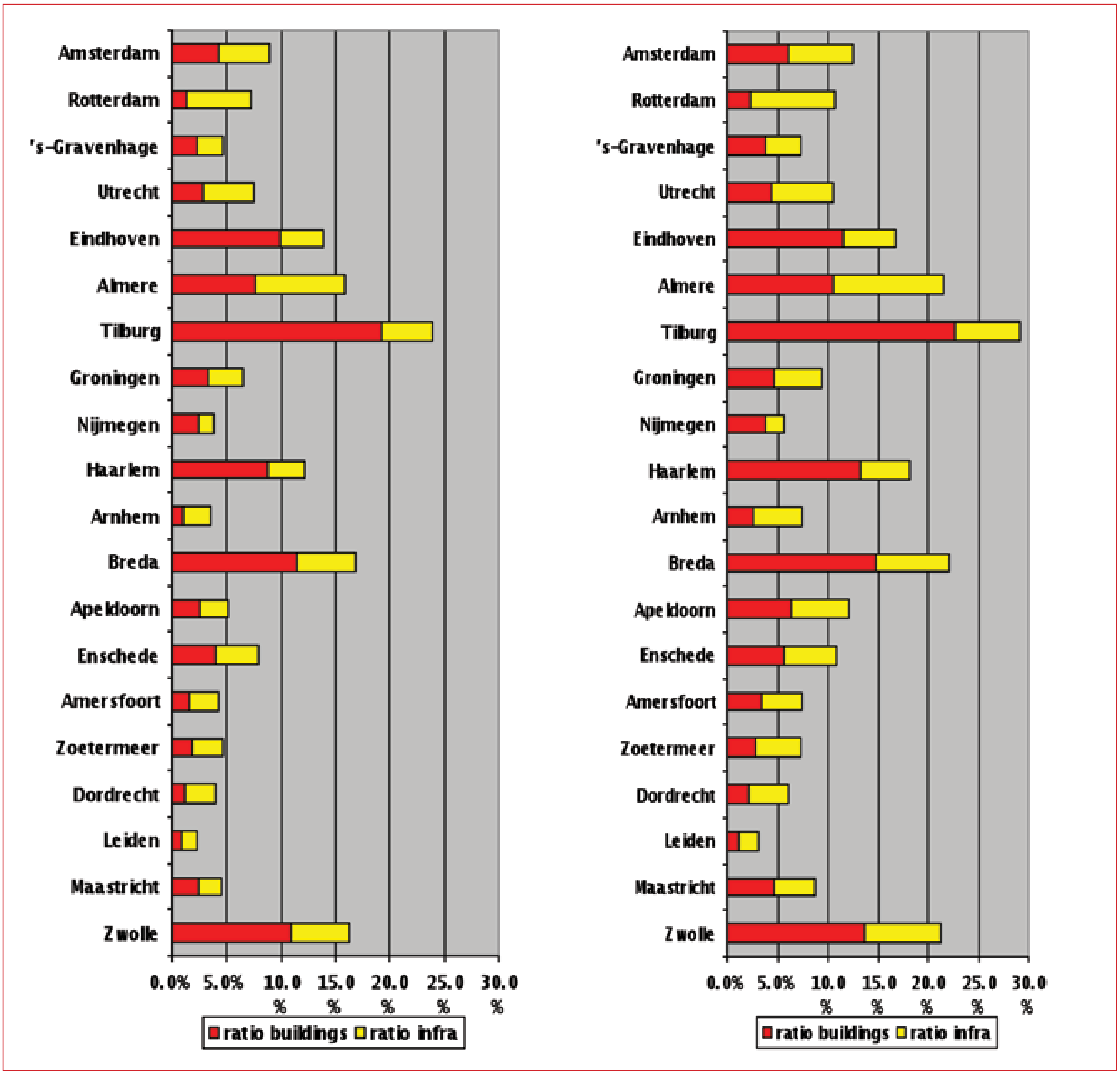


Figure 4.33 Ratio of the flood-affected building stock and infrastructural extent for a 54mm event (left) and a 77mm event (right)

The results from Figure 4.33 differ dramatically from those in Figure 4.30 and prove the effect of an almost random distribution of local depressions resulting in flood accumulation. Yet, the actual location of the building and infrastructure within cities is noticeable; apparently within the cities of Tilburg, Breda and Zwolle these are located on or adjacent to those areas in which flood accumulation occurs. Note though that the ratios are relative indicators. Since the housing stock in cities differs, a bias occurs towards smaller cities.

In conclusion, the outcomes of this second part of the study into pluvial flooding are difficult to generalize since no relation seems to exist between urban typology, location, size, etc. and the occurrence of flood accumulation.

This outcome seems to justify the conclusion that the level of morphological differentiation in combination with the distribution of urban function prevents identification of clear patterns in flooding. Location on flat areas apparently boosts the influence of small perturbations in morphology (minor local depressions).

4.3.5. Exposure to groundwater nuisance

The earlier mentioned changes in the climate will affect the shallow groundwater table in the following way:

- An increase in the total amount of rainfall will lead to higher groundwater tables and hydraulic heads in the underlying first aquifer. More areas in The Netherlands will become dependent on artificial drainage and therefore susceptible to groundwater nuisance;
- Higher river discharges will cause higher water levels and longer periods of high water levels in the river. Both will cause higher hydraulic heads in the first aquifer along side the large rivers. In areas where the confining holocene clay and peat layers are relatively thin (e.g. less then 5 to 10m thick), this may lead to a substantial increase of the groundwater table and urban areas bordering the rivers may endure more groundwater nuisance.

The way the shallow groundwater table reacts to changes in the amount of precipitation strongly depend on factors like the subsurface characteristics (geology), the groundwater flow system, the interaction between groundwater and surface water and the relationship between groundwater recharge and land use (e.g. paved areas have substantially less recharge then green zones). In general, the larger the distance is towards either open water or a subsurface drainage system, the stronger the groundwater table will increase during periods of high precipitation. Therefore the urban water system provides less possibilities for controlling groundwater nuisance, in areas where the distance towards these systems is relatively large.

The groundwater fluctuations will be more amplified in the higher sandy areas of The Netherlands. These sandy areas are fully drained by creeks. In particular in the lower part of these creeks the discharge will increase up to 9%, which will cause a rise in the groundwater tables (TNO, 2007). Besides an increase in groundwater nuisance, this may lead to inundation of the creek valleys. In polder areas the effect of an increase in rainfall will largely be buffered by the water system (canals), though urban areas with relatively few canals will encounter rising groundwater tables nonetheless.

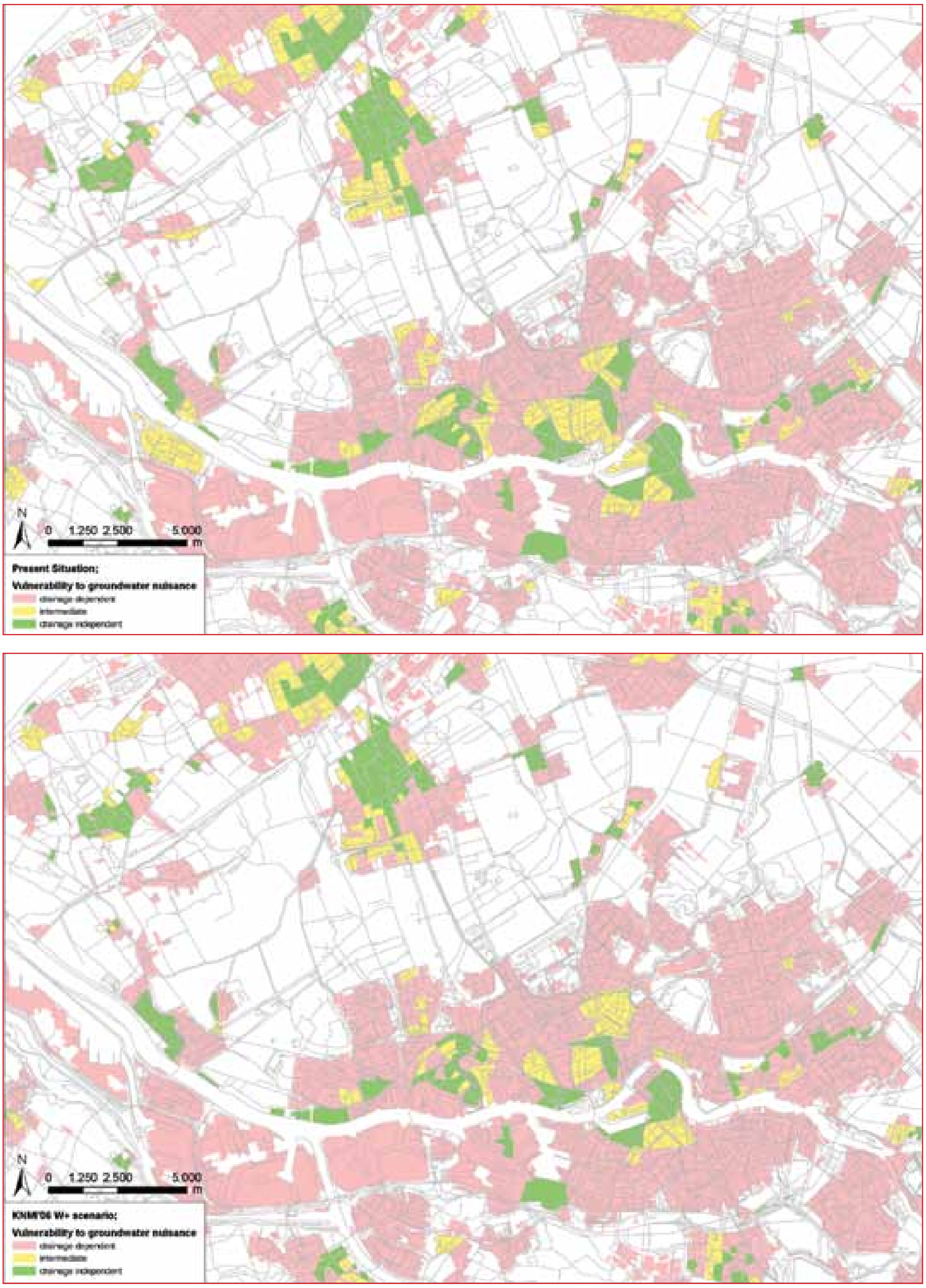


Figure 4.34 Indicative change in drainage dependency of urban areas (above: current situation; below: situation in the W+ scenario)

The change in groundwater levels and therefore the abundance of drainage dependent areas (Chapter 3) has been determined indicatively. It can be assumed that there is roughly a linear relationship between the increase of the amount of rainfall and the increase in groundwater levels. In the most extreme scenarios (W and W+, see section 4.1), the amount of rainfall will increase 7% to 14%. In figure 4.34 the change in the amount of drainage dependent areas is displayed for the region Rotterdam-Rijnmond. Also, the total urban surface area that is drainage dependent will increase in that order of magnitude. There will be only slight changes.

4.3.6. Sensitivity of urban functions to groundwater nuisance

When groundwater levels are structurally to close to the surface level, urban functions like buildings, roads and parks may be damaged. Also, the land subsidence occurring in clay and peat areas will cause the groundwater levels to get closer to the surface. Both will cause the drainage depth to decrease and therefore groundwater nuisance will occur. In literature, different criteria are given for the required drainage depth per urban function. Table 4.4 displays the overall guidelines, based on practical experience (SBR, 2007)

Table 4.4 Criteria for drainage depth

Urban Function	Required Minimal Drainage Depth (m below surface)
Main roads	1,00
Secondary roads	0,70
Gardens, parks and sports areas	0,50
Buildings (constructed with crawl space underneath)	0,70*
Buildings (constructed without crawl space)	0,50*

** Dependent on the floor level of the building and the thickness of the floor*

When the drainage depth of a certain urban area is too little, this area is classified as ‘drainage dependent’. Without additional (subsurface) drainage, the area is likely to be exposed to groundwater nuisance. In this study the analysis is made on neighbourhood level (Figure 4.38). The required drainage depth of buildings (0,7m) is considered to be most representative to determine the exposure to groundwater nuisance of a certain area, as buildings are most sensitive (see next section). The main problem with groundwater nuisance is the intrusion of moisture into the building, leading to damage of walls and floors by fungus as well as respiratory diseases to the residences. The damage caused by groundwater nuisance is only described qualitatively. There are no specific indicators available to quantify the damage caused by groundwater nuisance, since the subsequent damage to a building depends on many factors. In the next sections, the sensitivity for each urban function group is described.

It should be noted that certain problems mentioned earlier may be related to flaws in the construction of buildings like poor ventilation of the crawl space and basement, incorrect or malfunctioning pluming, leaking sewage systems, etc. Even if high groundwater levels are the cause of damage of a certain building, road or city park, there are numerous factors that might be causing it, like construction works close by (obstruction of groundwater flow by sheet piles) or changes in the surface water levels. It is not possible to pin point the effects of climate change on a possible increase in groundwater related to damage to urban functions.

Buildings

Not all buildings are sensitive to high groundwater levels. Since the ’90s legislation requires new buildings to be constructed with a water resistant ground floor. Traditionally the ground floor of houses would be made of wood and a crawl space underneath the floor would provide the necessary ventilation to keep the wooden ground floor sufficiently dry. Ground floors are nowadays constructed of concrete and a crawl space has lost its ventilation function. The sensitivity of new houses to groundwater nuisance is therefore limited. In particular, houses built before the ’60 are sensitive to groundwater nuisance, since they are all constructed with wooden ground floors and crawl spaces underneath.

Though houses built in between the ’60s and ’90s are mostly constructed with concrete ground floors, the regulation did not require the floor to be water resistant (crawl space hedge, openings for pipelines, etc.). From the ’80s and onward groundwater drainage systems are specifically applied in new urban areas, but the lack of proper maintenance has let to complains nonetheless. Buildings between the ’60s and ’90s are therefore sensitive as well, but form an intermediate category.

Roads and city parks (trees)

All roads and parks are sensitive to high groundwater levels. Though the life expectancy of roads is notably shortened in areas with high groundwater levels, roads are generally perceived as the least sensitive urban function to groundwater nuisance. Roads and city parks usually form a part of the public domain and are maintained by municipalities. The adaptive capacity is therefore larger than for privately owned buildings, since measures can be taken on a larger scale. Parks (and particular trees) are more sensitive to groundwater nuisance than roads. The sensitivity of trees is described in more detail in the following sections.

In areas with relatively few trees, these trees form an important scenic and ecological role. This concerns in particular large trees that form a 'carrier' for the main green structure in an urban area, mutually connecting different green structures in the public domain. These trees need to be maintained as long as possible to be able to play their connecting role.

For some parts of The Netherlands (especially in the West) the increased wetting caused by land subsidence already forms a problem for trees. Both the diminishing of the drainage depth because of the land subsidence (the surface is lowered and reaches closer to the groundwater level), but also the levelling of the surface to invert the land subsidence are harmful for trees. Both will lead to suffocation of the root system. The impact of suffocation strongly depends on the age of the tree, the species but also the magnitude and duration of the suffocation. This is again depended on the distribution and the depth of the root system. The increase of the Average Lowest Groundwater Level (indicated as GLG in Dutch) serves as an indicator for the sensitivity of trees to high groundwater levels for urban areas (Figure 4.35).

The flooding tolerance of trees is defined by the resilience the tree has to overcome suffocation. The tolerance mechanisms vary. Were some trees will shift to a different way of dissimilating certain sugars, others will undergo morphological changes to increase the air permeability of the tissue (aerenchym). Despite these adaptive mechanisms, no trees in The Netherlands can endure permanent anoxic circumstances in the root system. Suffocation of the root system will occur in a matter of months or even days, depending on the species of the tree. Beyond the growing season the period in which the roots may suffocate is generally longer, since the root system is then hardly active.

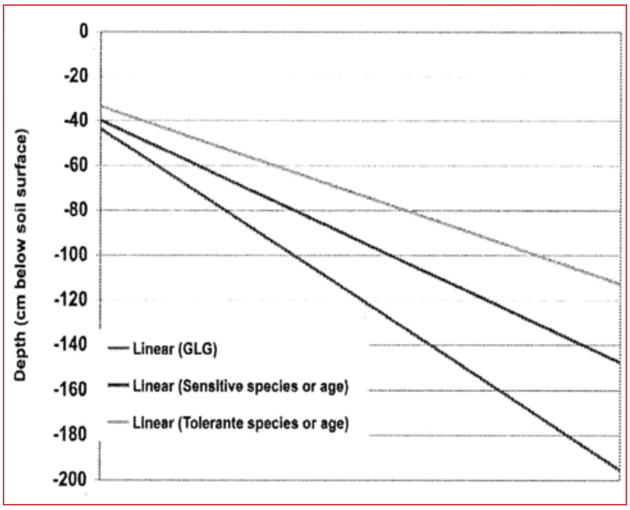


Figure 4.35 The maximum tolerable rise of the Average Lowest Groundwater Level (GLG) at various depth of the GLG (bottom line), for sensitive species(difference between bottom and middle line) and tolerant species (difference bottom and highest line). Source: Kopinga, 2009.

A tree's chances of survival after suffocation will strongly depend on the adaptability (and possibility) of the tree to form new roots in combination with the earlier mentioned flooding tolerance. This means that the available root space after suffocation needs to be large enough to grow new roots that anchor the tree once again. The new root system should also be able to take up sufficient amounts of nutrients to ensure the tree's survival. The survival changes also depend on the deterioration degree of the root system and the presence of parasite wood fungus.

4.3.7. Intrinsic vulnerability for groundwater nuisance

The vulnerability to groundwater nuisance of certain urban areas depends on the damage caused be a structural increase of the groundwater level. The presence of sensitive urban functions in drainage dependent areas makes these urban functions more vulnerable then if they would be in drainage independent areas. For buildings the age is an important factor that determines the sensitivity to groundwater nuisance. Table 4.5 presents the vulnerability matrix for groundwater nuisance, that is used to express the exposure and sensitivity of urban areas into the vulnerability to groundwater nuisance.

Table 4.5 Vulnerability matrix for assessing groundwater nuisance

Urban Function	Drainage dependent areas	Intermediate areas	Drainage independent areas
City parks	strong	substantial	limited
Roads	substantial	substantial	limited
Buildings before '60	strong	substantial	limited
Buildings from '60 to '90	substantial	substantial	limited
Buildings after '90	limited	limited	limited

The vulnerability is visualized by determining which sensitive urban functions are present in areas exposed to possible groundwater nuisance (usage of CBS neighbourhood map, the postal code building stock database and the TOP10 vector map, combined with results from the National Hydrologic Instrument). For each exposed neighbourhood the total number of buildings of a certain age are counted as well as the cumulative surface area of city parks and roads. This makes it possible to quantify the vulnerability to groundwater nuisance of urban functions (table 4.6).

Figure 4.36 presents the drainage dependency of the total urban area in The Netherlands in case of the W+ scenario. Figure 4.37 displays the main geographic regions of The Netherlands. There appears to be a clear relationship between the geographic region and the location of drainage dependent urban areas, when comparing Figure 4.36 and Figure 4.37. How and when groundwater nuisance occurs is therefore dependent on the geographic situation. Nonetheless, groundwater nuisance caused by to high groundwater levels occurs throughout the country, though lower lying neighbourhoods surrounding the city centre are usually more susceptible. It should however be noted that Figure 4.36 only expresses the *exposure* to possible high groundwater levels. Not all urban functions are sensitive to high groundwater levels. Moreover, new buildings are generally much less sensitive to high groundwater levels, because the ground floor has to be made water resistant nowadays (see previous section). Though many new urban areas are built in drainage dependent areas, this does not mean they are vulnerable to groundwater nuisance. Therefore, there seems to be no particular relationship with soil conditions or geographic situation and the vulnerability of urban areas to groundwater nuisance on a regional scale. Local factors are more determining. The overall *intrinsic vulnerability* of urban areas to groundwater nuisance is visualized in Figure 4.38, in which the sensitivity of urban functions is taken into account as well.

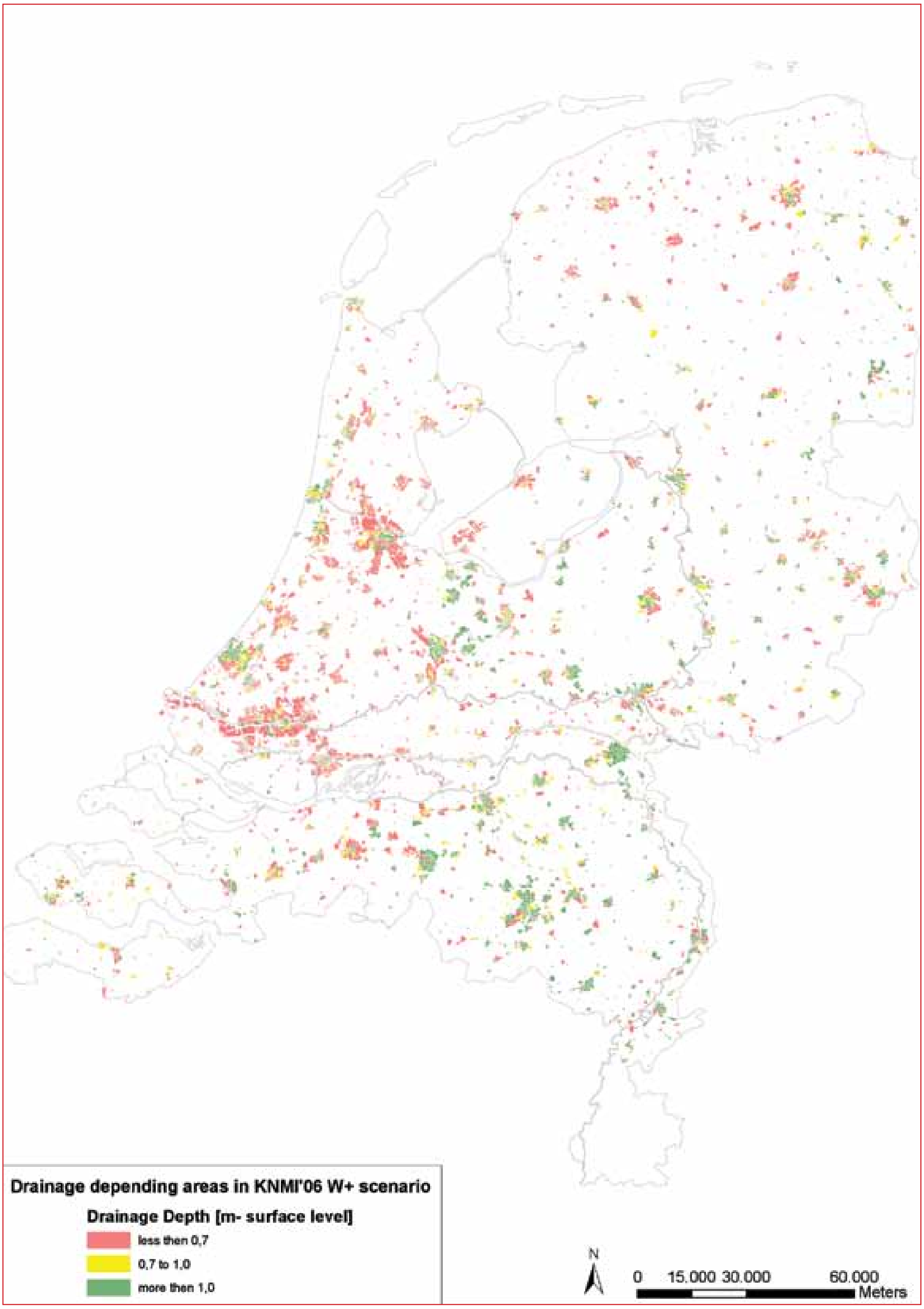


Figure 4.36 Drainage dependency of urban areas in The Netherlands

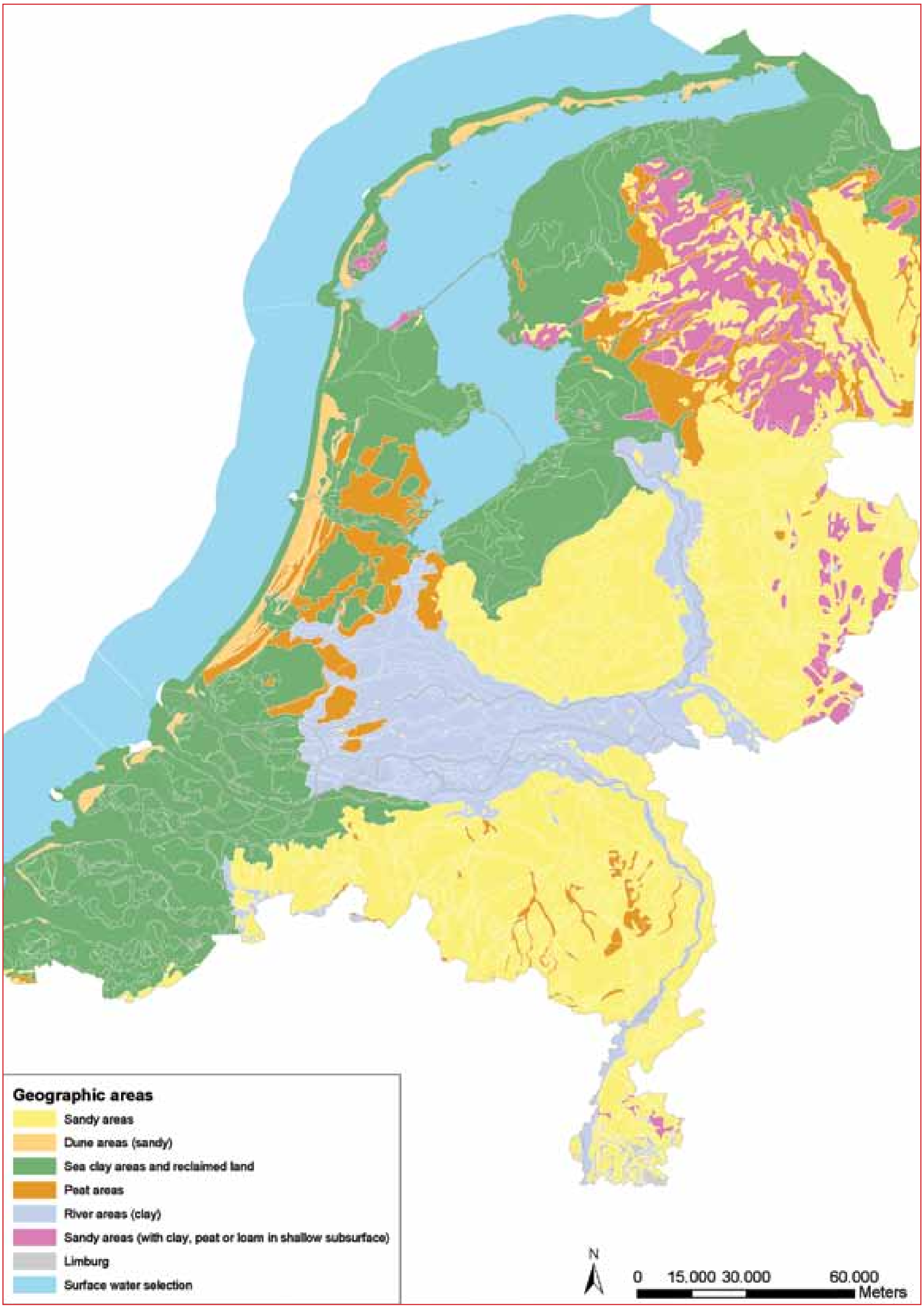


Figure 4.37 Main geographic regions in The Netherlands

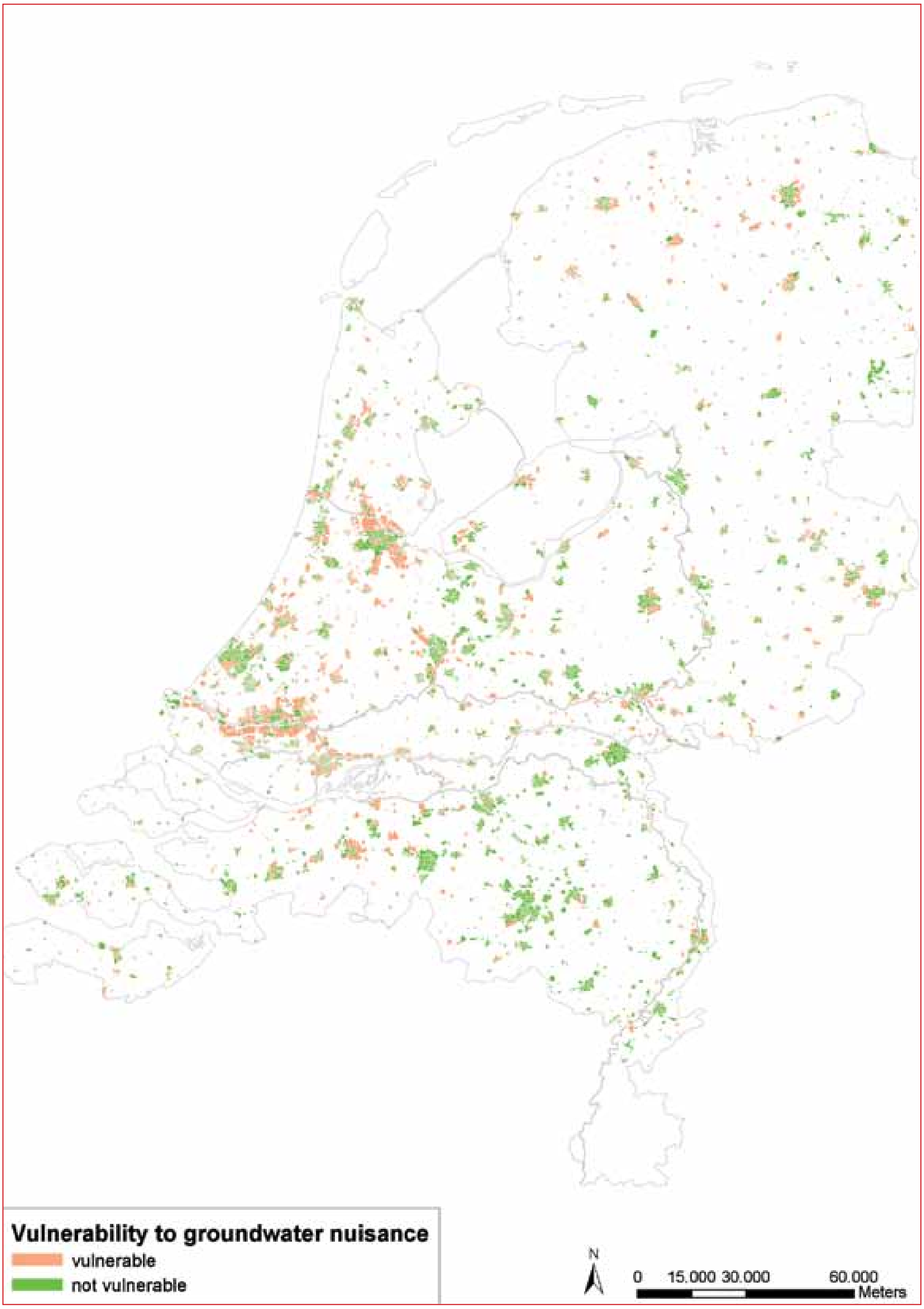


Figure 4.38 Vulnerability to groundwater nuisance of urban areas in The Netherlands

Table 4.6 Vulnerability of existing urban areas to groundwater nuisance

Urban Function	Drainage dependent areas	Intermediate areas	Drainage independent areas
City parks (ha)	16 611	4 781	10 101
Roads (ha)	16 968	6 032	118 142
Buildings before '60 (amount)	679 081	308 586	912 194
Buildings from '60 to '90 (amount)	1 527 709	604 342	1 098 134
Buildings after '90 (amount)	628 891	190 317	287 369
Urban Function	**Drainage dependent areas**	**Intermediate areas**	**Drainage independent areas**
City parks (ha)	53%	15%	32%
Roads (ha)	12%	4%	84%
Buildings before '60 (amount)	11%	5%	15%
Buildings from '60 to '90 (amount)	24%	10%	18%
Buildings after '90 (amount)	10%	3%	5%
	Vulnerable		
Urban Function	*Strong*	*Substantial*	*Limited*
City parks	53%	15%	32%
Roads	0%	16%	84%
Buildings	11%	39%	50%

From the analysis it can be concluded that half the buildings in the urban areas of The Netherlands are strongly or substantially vulnerable to groundwater nuisance, because they are sensitive and exposed to high groundwater levels. More than half the city parks are strongly or substantially vulnerable to groundwater nuisance. Roads are generally the least vulnerable urban function for groundwater nuisance, with less then 17% being just substantially vulnerable. In practice this will not necessarily mean that there is groundwater nuisance at these functions. In most cases drainage systems or leaking sewage systems keep the groundwater level sufficiently low. Nonetheless, in many cases the described drainage dependency is not always taken into account during reconstruction of roads and subsurface infrastructures. Since no public authority is explicitly responsible for maintaining a certain groundwater level, the overall attention to define, implement and regulate adequate policies and guidelines is limited.

The expected increase in the total annual rainfall (7% in W-scenario and 14% in W^+-scenario) and in particular the increase in the number of heavy rainfall events, will cause areas that already endure groundwater nuisance to be more exposed to longer and more often events of groundwater nuisance. Areas that may now be independent of (artificial) groundwater drainage may become exposed as well if the expected increase in rainfall occurs. This means that more areas and thus more urban functions will by vulnerable to groundwater nuisance in the future. The graduality (chapter 3) is linear, meaning that the amount of urban functions that will become more vulnerable will grow in the order of 7% to 14%, depending on the climate scenario.

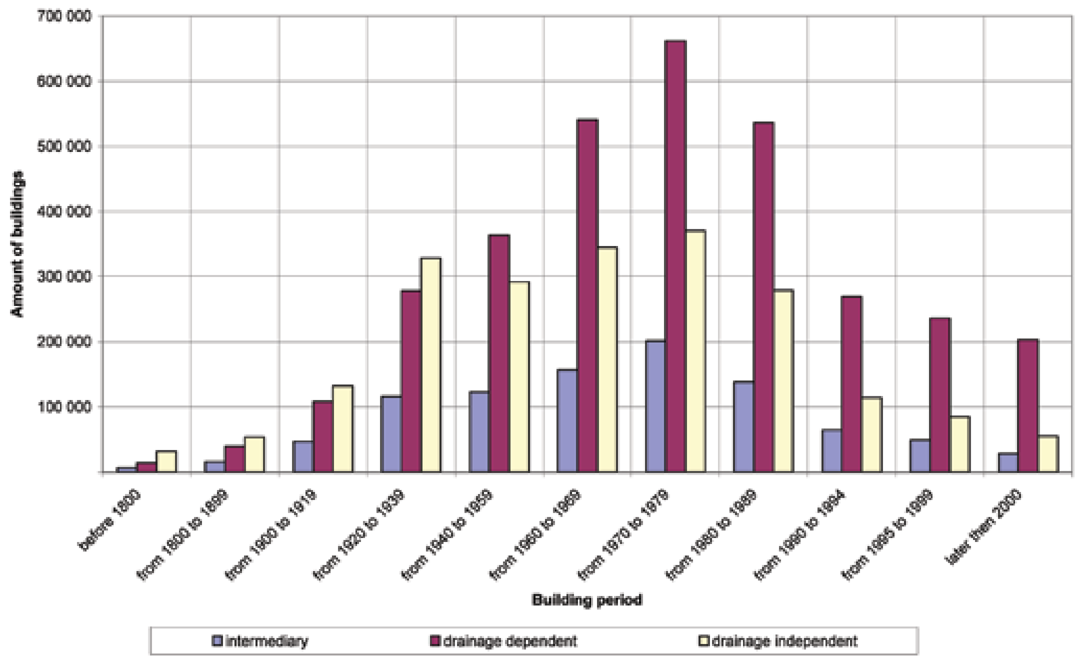


Figure 4.39 Graphical display of age and vulnerability of buildings to groundwater nuisance

The majority of the existing buildings in The Netherlands has been built between 1960 and 1980. After World War Two more buildings were built in drainage dependent areas than in drainage independent areas, which has been continued to this day (Figure 4.39). The ratio between the amount of buildings in drainage independent and drainage dependent areas stays however the same. Furthermore, buildings that were built after the '80 were generally constructed with water resistant ground floors and are much less sensitive to groundwater nuisance.

Table 4.7 presents the cumulative surface area of future urban functions (drawn from expected plan developments, NIROV, 2009) in drainage dependent and drainage independent areas. Adequate technical measures and construction methods are readily available to prevent groundwater nuisance in new urban areas.

There is a strong need for plan developers and competent authorities to actually implement a robust and climate proof design of these new areas. The fact that 84% of the new urban areas will need special attention to limit the vulnerability to groundwater nuisance, underlines this.

Table 4.7 Vulnerability of new urban areas until 2050 for groundwater nuisance

Type of new urban areas	Total surface area in drainage dependent areas (ha)	Total surface area in intermediate areas (ha)	Total surface area in drainage independent areas (ha)	Total surface area new urban areas (ha)
Enterprises	19 763	1 594	2 238	23 594
Retail	44	25	69	138
Mixed urban	7 744	463	1 900	10 106
Offices	1 138	300	444	1 881
Roads	1 588	300	563	2 450
Residential	24 319	2 825	6 138	33 281
Total	**54 594**	**5 506**	**11 350**	**71 450**
Percentage total	*76%*	*8%*	*16%*	

4.3.8. Conclusions for water nuisance

The previous outcomes and observations lead to the following set of conclusions in relation to *pluvial flooding*:

- For moderate rainfall events, land cover differences generate relatively similar runoff levels; the influence of the urban layout is relatively small;
- For moderate events, there is a significant difference in runoff levels between cities located on sand based and clay based soil groups;
- With the exception of downtown areas, for extreme events, no strong relation exists between the land cover distribution in urban typologies and observed runoff levels; the influence of strong rainfall differs per region;
- Runoff levels for Industrial areas differ substantially;
- Because of saturation, extreme events show an increasing effect on cities located on sand layers; frequent events result in quicker flooding of cities located on clay soils;
- For downtown areas the expected runoff shifts towards higher levels for extreme events;
- Within urban centres the observed runoff levels shift almost uniformly when precipitation are increased; Many areas which might appear to be prone to large runoff levels (e.g. industrial areas) show only weak correlations with runoff generation; increasing generation of runoff because of extreme events does not generally apply;
- The absence of strong morphological differences (elevation levels) makes it difficult if not impossible to distinguish a relation between urban characteristics and flood accumulation;
- The building stock and infrastructural extent in a subset of major cities seems exposed to flooding. This set consists of the cities of Tilburg, Almere, Breda, Eindhoven and Zwolle.

Additionally, several conclusions can be made after identification of *groundwater related flooding*:

- There is a clear relationship between the dynamics of the groundwater and surface water systems and the features of the different geographical regions in The Netherlands. How and when groundwater nuisance occurs depends on the geographic situation.
- Nonetheless, groundwater nuisance caused by too high groundwater levels occurs throughout the country, though lower lying neighbourhoods around the city centre are usually more susceptible. There seems to be no particular relationship between the geographic region a city is situated and the *occurrence* of groundwater nuisance. Local factors are more determining.
- Buildings older than 1990 and in particular older than 1960 are vulnerable, as well as trees in urban parks in drainage dependent areas.
- After World War Two, more houses were built in drainage dependent areas than in naturally discharging areas.

In general, the larger the distance is towards open water or drainage systems, the more exposed an area will be for (ground)water nuisance and the less possibilities a water system provides to control it.

4.4. Drought

4.4.1. Effects of climate change

The expected increase in drought (increase in rainfall shortage) during the summer periods will intensify the normal decline of the groundwater table during these summer periods. In some areas the annual average lowest groundwater level (indicated as GLG in Dutch) will be structurally lower; the replenishment of groundwater during the (wet) winter season will not be sufficient. Urban areas will therefore be more exposed to drought in the future.

4.4.2. Exposure

To determine the exposure of urban functions to drought, the following aspects have to be considered:

- Damage to historical buildings in clay and peat areas is directly related to the decline of the groundwater level. However, it is not just a single decline of the groundwater table that causes damage, but more the change in the yearly dynamic of the groundwater level as well as an average decline (see next section). There are no scenario calculations for the change in the groundwater dynamics jet available on a national scale.
- To determine the impact of drought on wooden piled foundations of buildings (see next section) it is necessary to have some degree of insight in the variability of the construction levels of the wooden piled foundation. Though information can be obtained, it requires a large scale inquiry in which all municipalities within clay and peat areas provide all necessary information.
- Land subsidence can have an impact on some historical buildings and (subsurface) infrastructure. Land subsidence is a common process in clay and peat areas. The clay and peat layers in the subsurface shrink because of drainage, which invokes the land subsidence. This

process will be enhanced by more extreme drought as expected in the climate change scenarios (KNMI, 2006). It is not known how much more land subsidence will occur when the predicted droughts cause a decline of the groundwater table.

- Also city parks and trees may endure damage caused by extreme drought. This relates to the depletion of the soil moisture content and the increase of the salinity in the soil surrounding the roots (see next section). Many of the polder areas in the west and north of The Netherlands are below sea level and are artificially drained. The draining attracts deep groundwater with a high salt content (former seawater). Though it is known where the salinity will increase, it is not well understood to what degree climate change will result in a local increase of the salinity in the root systems of trees in the future. Furthermore, there is no sufficient information available on a national scale to determine the depletion of the soil moisture content in the root zone of trees.

It is therefore not possible to quantify the exposure to drought on a national scale at this stage. There is no spatial information available to adequately describe the drought impact on city parks and trees. The exposure to drought on city parks and trees can therefore not be visualized. In this study only the presence of historical buildings in clay and peat areas serve as an indicator for the vulnerability of urban areas to drought.

Obviously, a supply of water can compensate the effects of drought, though this is not always easy to achieve in existing urban areas. In general, the less the distance is towards open water or water storage facilities, the more possibilities the water system provides to compensate the effects of drought.

4.4.3. Sensitivity

This section described the processes that determine the sensitivity of certain urban functions in more detail.

Historical buildings

In clay and peat areas in the western and northern part of The Netherlands, the buildings are generally built on piled foundation because of the ongoing land subsidence in these areas. To prevent the buildings from subsiding as well, the foundation piles are slain up to the stable pleistocene sands. In the past (up to the '50s) wooden foundation piles would be used, where nowadays concrete is normally applied (Figure 4.40).

As long as the wooden foundation piles stay completely underneath the groundwater table, they will not deteriorate. When oxygen becomes available, fungi present in the wood will grow and deteriorate the wood (also bacteria can cause damage to the wooden foundation piles, but this is not related to the lowering of the groundwater level). Normally, the wooden foundation piles would be placed at a depth lower than the lowest recorded groundwater table in a certain place. Different factors may cause the groundwater level to lower further and the head of the foundation pile may fall dry occasionally. Also the expected extreme drought inflicted by climate change may enhance the decline of the groundwater table and spark the deterioration of the wooden piled foundation. The damage will not occur directly. The foundation piles can endure a cumulative period of drought of up to 10 to 15 years, before the bearing

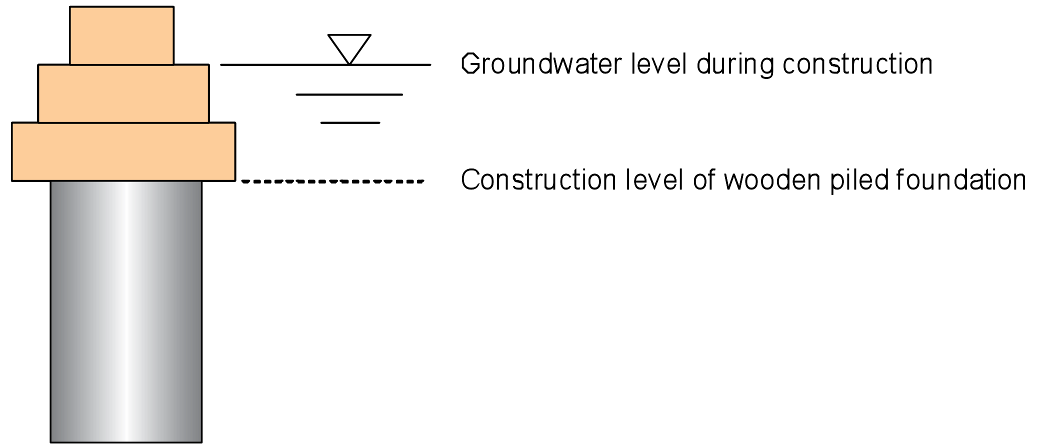


Figure 4.40 Construction level of piled foundation and groundwater level

capacity is strongly reduced (SBR, 2006). It is in most cases not possible to determine to what degree a foundation has endured a certain period of drought. It is therefore not possible to express the current state of the historical buildings in this study. Still, it is possible to conclude that there will be more damage to historical buildings on wooden piled foundation in clay and peat areas, if the predicted drought related to climate change occurs.

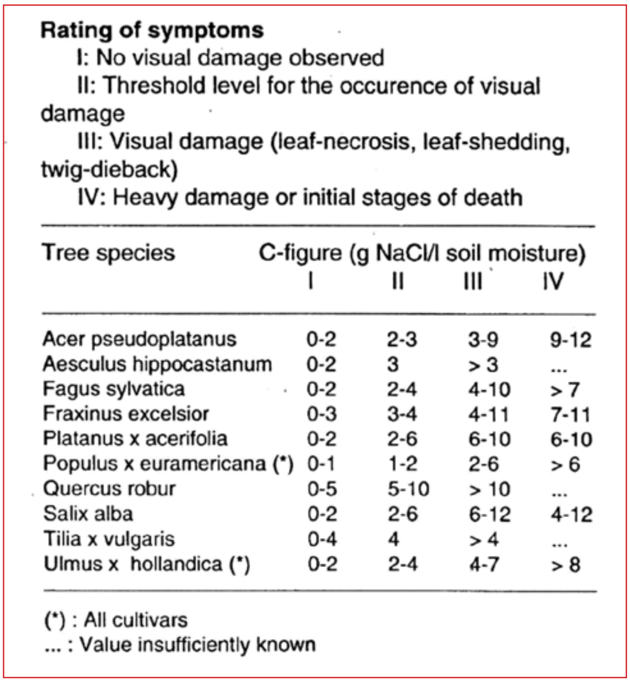
Some historical buildings were not built on piled foundation, nor are most streets and subsurface infrastructure. In clay and peat areas these urban functions will subside together with the shrinking clay and peat layer and can be damaged. The effects are particularly notable in areas where the clay and peat is present in the shallow subsurface as opposed to areas where the clay and peat layers are present more deeper in the subsurface.
There are different ways in which land subsidence can cause damage to urban functions:

- Differential land subsidence: the least damage will occur if an entire area subsides equally, but this is almost never the case. Generally differential land subsidence occurs. Differences in pressure or in soil conditions will lead to different degree of land subsidence. This results in shear stress to buildings and subsurface infrastructure without foundation piles and ultimately damage.
- Negative shear stress: the shrinking of the clay and peat layers occurs around foundation piles as well as anywhere else. This will result in shear stress around the foundation piles. In some cases the foundation pile is pulled away, which will cause damage to the building.
- Because the surface level is lowered, it will reach closer to the groundwater level which in turn may lead to groundwater nuisance (see previous section).

It should be noted that land subsidence is an autonomous process. More intense drought related to climate change will enhance the land subsidence, but also other processes may cause the speed of land subsidence to increase (e.g. more intense groundwater draining).

City parks (trees)
City parks and particular trees may endure damage caused by drought. The drought tolerance of trees depends on the species as well as the tree's surrounding conditions:

- Species of trees: for some species the tolerance to drought is based on (partially) reducing the evaporation in case of strong sun radiation, even if there still is enough water supply. Other species react less on sun radiation and keep on evaporating until the water supply in the root zone is depleted. The subsequent tolerance of the tree to drought depends on the ratio between the size or mass of the root system (in the subsurface) and the total mass of the leaves in the canopy (above ground). The larger the root system is compared to the canopy, the more tolerant the tree is for drought. Furthermore, the total amount of water that a tree evaporates on an average (summer) day per leave surface area as well as the Leaf Area Index (LAI), determine the tolerance to drought and can vary significantly for each species.
- Soil moisture content (surrounding conditions): every species of tree can flourish in areas where the water supply to the root system is provided by groundwater throughout the year. This is generally the case in the lower lying clay and peat areas with shallow groundwater tables. The higher sandy areas have deeper groundwater tables which in most cases are out of reach of the root systems. In those areas the trees are fully dependent on the infiltrating rainwater either stored in the root system beyond the growing season or replenished by rainfall throughout the year. There are also intermediate areas where the groundwater fluctuations make it only a part of the year possible for trees to depend upon groundwater for the water supply. In the latter two areas the soils' storage and yield capacity for moisture, are the distinctive factors that determine to what degree the surrounding conditions make the tree sensitive to drought. The root systems of trees are adapted to the surrounding circumstances. The KNMI 2006 climate scenarios presume a shift in the rainfall distribution throughout the year, where summer will become dryer and winters wetter.
- Salinity (surrounding conditions): the expected increase in the salinity of the water system during dry periods, related to salty seepage in the western and northern polder areas of The Netherlands, will cause damage to existing trees. Critical situations will occur when the salt content in the soil moisture increases up to more then 1 or 2g/l for species that are highly sensitive to salt. More tolerant species can endure up to 8 g/l or more without significant problems (see Table 4.8).



Rating of symptoms

I: No visual damage observed

II: Threshold level for the occurence of visual damage

III: Visual damage (leaf-necrosis, leaf-shedding, twig-dieback)

IV: Heavy damage or initial stages of death

Tree species	C-figure (g NaCl/l soil moisture) I	II	III	IV
Acer pseudoplatanus	0-2	2-3	3-9	9-12
Aesculus hippocastanum	0-2	3	> 3	...
Fagus sylvatica	0-2	2-4	4-10	> 7
Fraxinus excelsior	0-3	3-4	4-11	7-11
Platanus x acerifolia	0-2	2-6	6-10	6-10
Populus x euramericana (*)	0-1	1-2	2-6	> 6
Quercus robur	0-5	5-10	> 10	...
Salix alba	0-2	2-6	6-12	4-12
Tilia x vulgaris	0-4	4	> 4	...
Ulmus x hollandica (*)	0-2	2-4	4-7	> 8

(*) : All cultivars
... : Value insufficiently known

Table 4.8 Critical amount of the C-number (=gram NaCl per liter soil moisture) where no (I) light (II), visual (III) damage or death (IV) occurs for a number of common species of deciduous trees (Source: Kopinga & van den Burg, 1995).

Except the earlier mentioned aspects, the tolerance for drought of trees also depends on the spatial design in which the trees are planted. A solitaire tree will evaporate about 1,5 times more than the same tree in a forest. The way trees are spatially distributed (presence of roads and buildings) plays a role in the amount of water available in the root zone during the growing season. Soil sealing of urban areas prevent rainfall from infiltrating and replenishing both the groundwater and the soil moisture content in the root zone. Therefore, soil sealing enhances the impact of drought.

Though depletion of the soil moisture content is expected to increase during extreme periods of drought, it is difficult to say how many trees will not survive these expected extreme droughts.

4.4.4. Intrinsic vulnerability to drought

The exposure to drought and the sensitivity to various urban functions can only be qualitatively given, as described previously. Only for historical buildings some degree of spatial information is available to express the vulnerability. The following criteria are used:

- Neighbourhoods in infiltration areas, in which the shallow subsurface is highly sensitive for land subsidence (presence of many clay and peat layers) and have an average building stock older than 50 years are considered strongly vulnerable.
- Neighbourhoods in infiltration areas, in which the shallow subsurface is substantially sensitive for land subsidence (presence of some clay and peat layers) and have an average building stock older than 50 years are considered substantially vulnerable.
- Buildings in any other neighbourhood are considered not vulnerable to drought.

In Figure 4.41 the vulnerable neighbourhoods are visualized for the whole of The Netherlands. The clay and peat areas are mainly in the western and northern part of The Netherlands, which can be translated to the presence of vulnerable historical buildings. In Table 4.9 the number of vulnerable buildings are presented. One third of the historical buildings in The Netherlands are vulnerable to drought. Many owners choose to adjust the foundation of their historical building if present in clay or peat areas as soon as damage occurs. The wooden piled foundation will then be made resilient to the lowering of the groundwater table (eg. by replacing the wood of the head of the piled foundation with concrete). Though many of the vulnerable historical buildings may already have endured drought damage, this number is likely to increase notably, leaving the owners with a substantial financial burden (restoration costs of wooden foundation piles normally exceed € 40.000 per building, roughly 10 to 30% of the total value of the building). Many historical buildings are privately owned.

Table 4.9 Table of historical buildings vulnerable to drought

Exposure	Amount of Sensitive Buildings (before the '60)	Percentage
Strong	267 084	14%
Substantial	350 664	18%
Not	1 282 113	67%

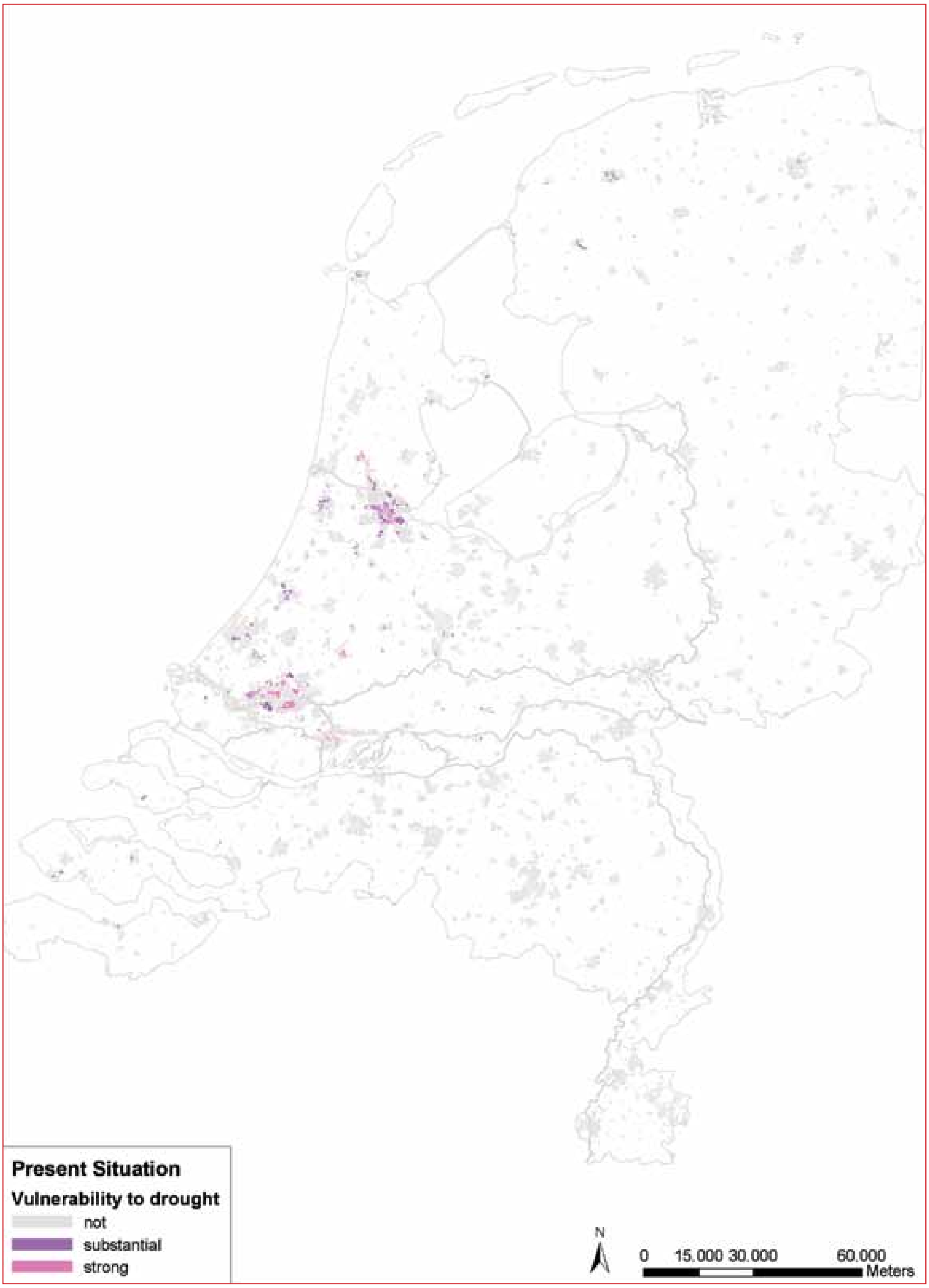


Figure 4.41 Map of historical neighbourhoods vulnerable to drought

4.4.5. Conclusions for drought

- One third of the historical buildings in The Netherlands is vulnerable to drought. Since climate change will cause an increase in drought it can be expected that the number of historical buildings that are damaged will rise.
- The cost of restoration of wooden piled foundations are substantial. This will forms an enormous financial burden on house owners.
- The vulnerable historical neighbourhoods are situated in the clay and peat areas of the western and northern parts of The Netherlands.
- Land subsidence caused by drought will increase, though it is unknown to what extend this will damage urban functions.
- Though depletion of the soil moisture content is expected to increase during extreme periods of drought, it is difficult to say how many trees will not survive these expected extreme droughts.
- Soil sealing of urban areas prevent rainfall from infiltrating and replenishing both the groundwater and the soil moisture content in the root zone. Therefore, soil sealing enhances the impact of drought.

4.5. Heat stress

4.5.1. Exposure of urban typologies to heat stress

The modelling results for heat exposure are based on those described in appendix A. Calibration has been performed using average surface temperatures retrieved from 15 Landsatthermal infrared images (Zwart, 2009; Klok et al, 2010) for a mean temperature of 20°C, using the city of Rotterdam as a case study. The resulting graph indicating the temperature deviations from the mean air temperature are depicted in Figure 4.42 and Figure 4.43 shows the actual Landsat ETM data which provided the basis for calibration.

Both the figures show maximum heating effects in the industrial (port) areas of Rotterdam. What is noticeable is that the cooling effect of the river is minimal. This is probably because neighbouring objects only marginally affect surface temperatures. One of the most important observations is that the surface temperature seems to a large degree dependent on land cover (and therefore indirectly on land use). Large continuous paved areas (as can be witnessed in the industrial zones) show maximum heating effects, while surface water and (larger) green zones provide cooling.

Figure 4.42 Expected surface temperatures for the Rotterdam urban extent with an input temperature of 20 °C.

Figure 4.43 Average surface temperature distribution (K) of Rotterdam based on 15 Landsat images (Zwart, 2009; Klok et al., 2010)

Again, the question is if these results are representative for all urbanized areas in The Netherlands. Therefore, the calibrated model has been applied to the urban extent of all municipalities with more than 30.000 inhabitants, after which a statistical analysis was applied. The distributions of temperature deviation for a subset of urban typologies (Ritsema van Eck, 2009) are depicted in fig 4.44. The depicted subset is based on anticipated relations between urban typologies and temperature deviation. Note that the average mean temperature, which served as input, remained at 20°C.

The outcomes show some important characteristics that differ from the anticipated relations. The first observation is that for industrial areas including office zones significant amounts of heat stress can be noticed. Yet, for smaller or peripheral areas, the distribution is almost even; in some areas a cooling effect can be noticed while other heat up. Furthermore, the heating effect anticipated from the Rotterdam case study is much less dramatic. The peak within the distribution is located around a deviation of +4°C. To some extend these outcomes also hold for the downtown areas. While for downtown residential areas the heating effect is still moderate, the peak for the complete downtown area is located in the upper end of the range (+7°C). Surprisingly, this extends to village and suburban centres. The distribution for garden cities ('wonen bij stedelijk groen') is relatively uniform.

Both heating and cooling effects are observed. A clear cooling effect is shown for urban green zones and recreation facilities ('groen en sportvoorzieningen').

If looking at the complete set of 19 urban typologies and their respective distributions, 12 show a shift towards a positive temperature deviation. Apart from the already mentioned green zones/recreation area, a cooling effect is observed for major infrastructure areas ('Grootschalige Infrastructuur'). This might seem unusual. Yet, this can be easily explained. Since main infrastructural areas (highways) are mostly surrounded by green zones that act as buffers towards residential and working areas. These green zones are included in the calculations. Apparently, the aggregate cooling effect of the green zones is larger than the heating effect of the road surfaces. Almost uniform distributions are found for building areas ('Bouw- en Stortterrein'), public services ('Openbare en Sociaal-Culturele Voorzieningen') and the earlier mentioned green housing areas ('Wonen bij Stedelijk Groen'). On average the variance within the distributions is limited.

Thus far, the analysis has remained static; the results have been analyzed for a single average input temperature. One of the main concerns for urban heat stress though is that for higher temperatures, the temperature deviation shows some multiplier effect, consequently increasing the cooling and heating effects of land cover. To test this assump-

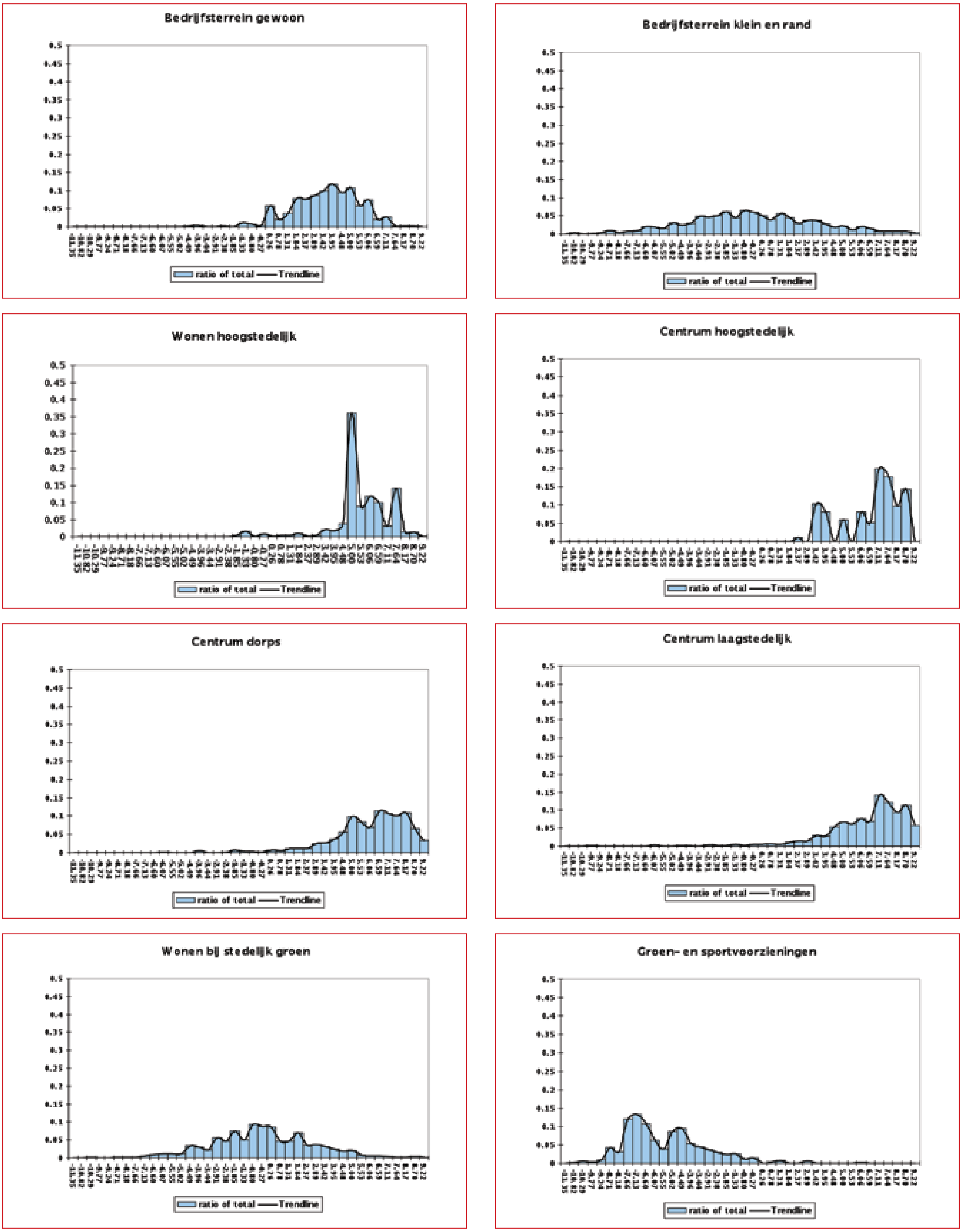


Figure 4.44 Heat distributions for 8 urban typologies

tion, the input temperatures have been increased to respectively 25, 30 and 35°C, after which the model has been run using the same level of detail as before. The distributions for the aggregate urban typologies are depicted in fig 4.45 and set out against the earlier ambient temperature level of 20°C. Descriptive statistics are provided in Table 4.10 and the results are shown in Figure 4.45.

One of the main features that can be observed from Figure 4.45 is degradation of the peak in the distribution. While for an ambient temperature of 20°C a clear peak can be observed around +2.5°C (so effectively 22.5°C), the distribution 'flattens-out' for input temperatures of 25 and 35°C. Thus, the variance within the distribution increases; the standard deviation increases from 2.59°C (20°C) to 5.39°C (35°C). Furthermore, the peak in the distribution shifts towards the right (i.e. higher temperature levels) indicating an increasing heating effect compared to the mean input temperature. This also can be observed in the mean temperature deviation that increases from 0.35°C (20°C) to 2.55°C (35°C). To some degree, the left tail of the graph is also extended indicating an increased amount of areas in which a cooling effect can be observed.

Although the amount of data is limited, there seems to be a linear relationship between the ambient temperature and the observed mean temperature deviation ΔT_m:

$$\Delta T_m = 0.148T - 2.595 \quad (2)$$

Where T is the ambient temperature. The error margin for eq. 2 is 0.02, with a correlation coefficient of 0.99.

Table 4.10 Descriptive statistics for expected surface temperature deviations

Ambient Temperature	20 °C	25 °C	30 °C	35 °C
Min.	-9.75 °C	-10.06 °C	-11.35 °C	-13.5 °C
Max.	+5.25 °C	+7.50 °C	+9.75 °C	+12.00 °C
Mean	+0.35 °C	+1.07 °C	+1.82 °C	+2.55 °C
Std. Dev.	2.59 °C	3.58 °C	4.40 °C	5.39 °C
95% Conf. Interval	[-4.87 °C - +5.25 °C]	[-5.23 °C - +7.50 °C]	[-6.60 °C – +9.75 °C]	[-6.49 °C - +12.00°C]

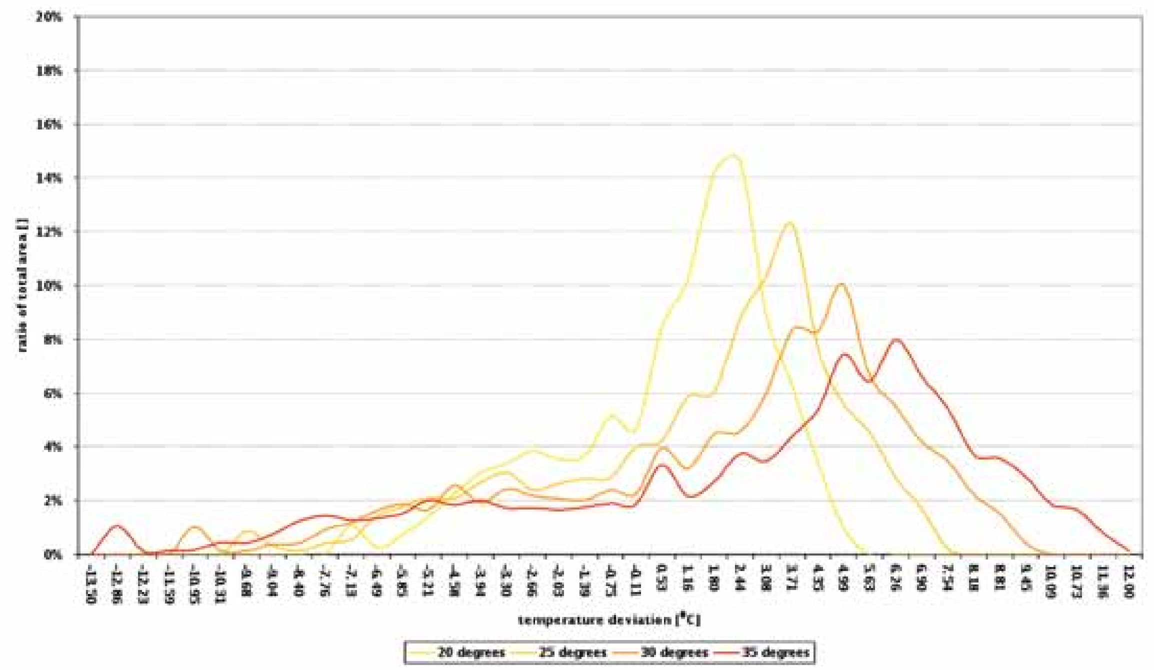


Figure 4.45 Heat distributions for different mean temperature levels

4.5.2. Exposure to heat stress over space

Except a quantitative analysis, a spatial representation of temperature distribution could provide further input for defining correlation or pattern formation. For a 20°C ambient temperature, the results are depicted in Figure 4.46.

As can be expected from the applied model, no clear regional differences can be observed. Nevertheless, the figure clearly shows the differences between the (hotter) urban extent and the (cooler) surrounding rural areas. Furthermore, in many of the cities, the centre areas indicate a heating effect. However, some of the cities also show hotter zones around the perimeter of the urban extent. These indicate mostly industrial areas.

Note that many of these fall within the typology: industrial and office areas ('Bedrijfsterreinen Gewoon') instead of the one indicating business areas in the periphery. Hence the observation is not necessarily in conflict with the earlier one on business areas in the periphery.

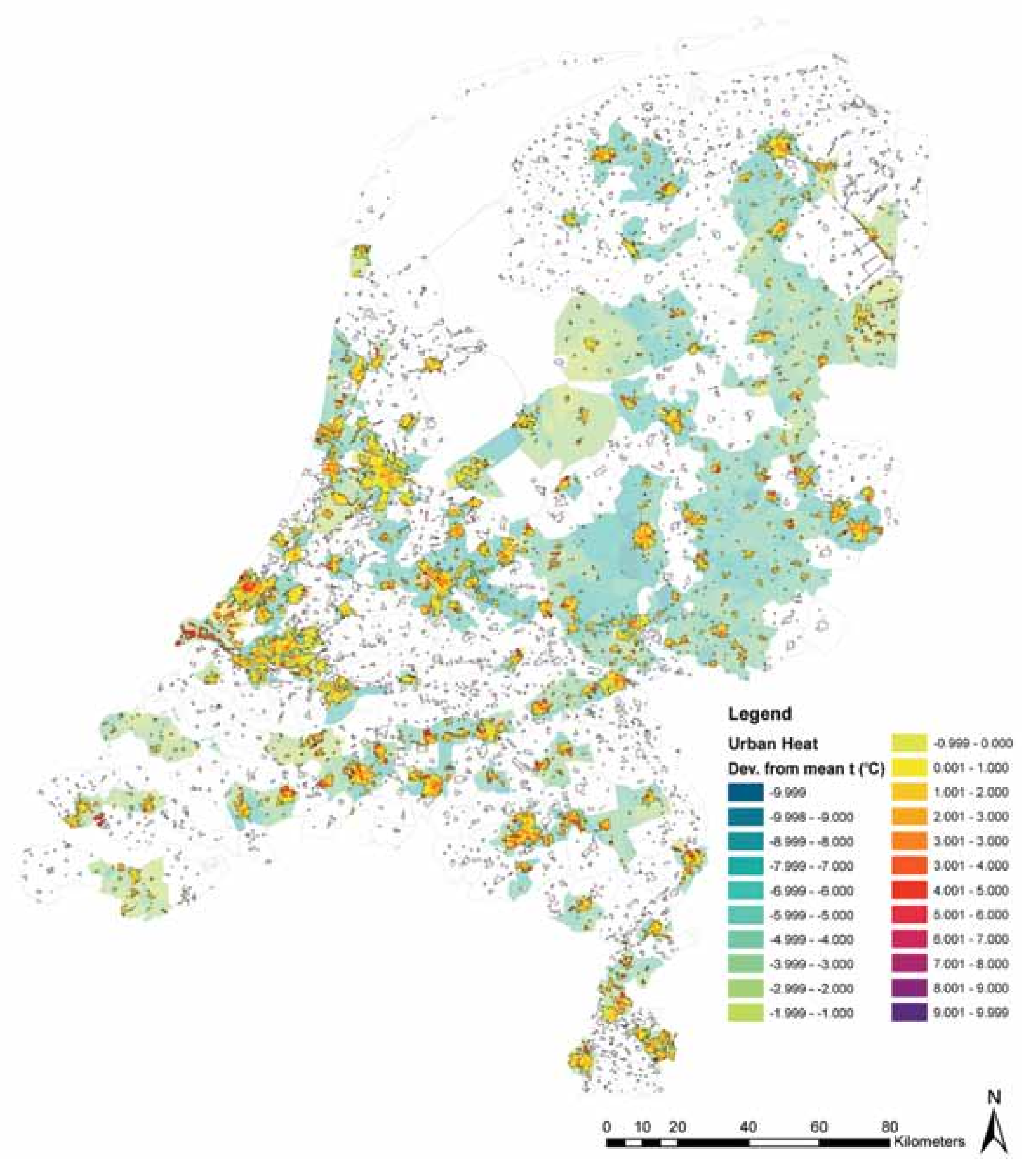


Figure 4.46 Spatial distribution of surface heat with a mean temperature of 20 °C

Graduality and convexity

The tendency of the temperature deviation distributions to become uniform during increasing ambient temperatures should be represented in the graduality calculations. If the distribution would merely shift towards higher temperature levels (i.e. to the right), the graduality of the value sets should be high. In this case though, the 'flattening' of the function should be expressed in lower graduality values indicating a disproportional heating or cooling effect. Note that this assumption does not contradict with the linear relation of the mean temperature deviation expressed in eq. 2; the mean does not express anything about the distribution. The graduality has been calculated for the 19 individual urban typologies from which a similar subset as in Figure 4.44 is depicted in Figure 4.46.

The 95% confidence level, which provides insight into the representative range of the distribution is [0.505 – 0.745]. This range is almost equal to the range for the topic of pluvial flooding and expresses a somewhat moderate level of graduality. The individual differences between the distributions are more dramatic. While a thorough discussion of the individual graphs is outside the scope of this study, it is important to note that the graduality for the most heat sensitive areas (i.e. downtown areas) is above average. This seems intuitive since these contain large levels of impervious surfaces that should induce heat stress. On the other hand the values for these typologies should not be overestimated; peaks in graduality for these typologies appear around 0.7. As for more issues related to the topic of heat stress, further empirical evidence should be collected before any final claims can be made.

One of the most interesting aspects of the calculations is the level of convexity (see Table 4.11). A substantial 91.8% of the temperature deviation functions is concave. This implicates that the heat stress effect becomes smaller during higher levels of ambient temperature; a 5 degree increase during an ambient temperature of 20°C results in a higher deviation than similar increase during an ambient temperature of 30°C. This seems intuitive.

Table 4.11 Descriptive statistics for graduality and convexity of expected surface temperature deviations

Min	0.328
Max	0.745
Mean	0.629
Std. Dev.	0.057
95% Conf. Interval	[0.505-0.745]
Convex	8.2%
Concave	91.8%

From Surface Temperature to Urban Heat Island

Finally, it is important to stress that the surface temperature acts as a mere indicator for the expected air temperature. The extreme differences in temperature between surface areas are expected to be flattened out to some extend, decreasing the variance within the temperature distribution. Furthermore, the perceived trend shift in mean temperature deviation might be overestimated. Since research on urban heat stress in The Netherlands is in its infancy, the relation between surface temperature and air temperature cannot be validated through empirical observations. Furthermore, scaling effects (city size), the influence of location aspects (proximity to the sear or large water bodies) and low level aspects (use of materials in buildings and public space) is omitted in this study. These factors might have a significant impact on the actual level of urban heat stress for increasing ambient temperatures. Nevertheless, it is important to provide a first assessment of heat stress differentiation using actual urban data, which provides insights in the relation between urban typologies, layout and the resulting temperature distribution.

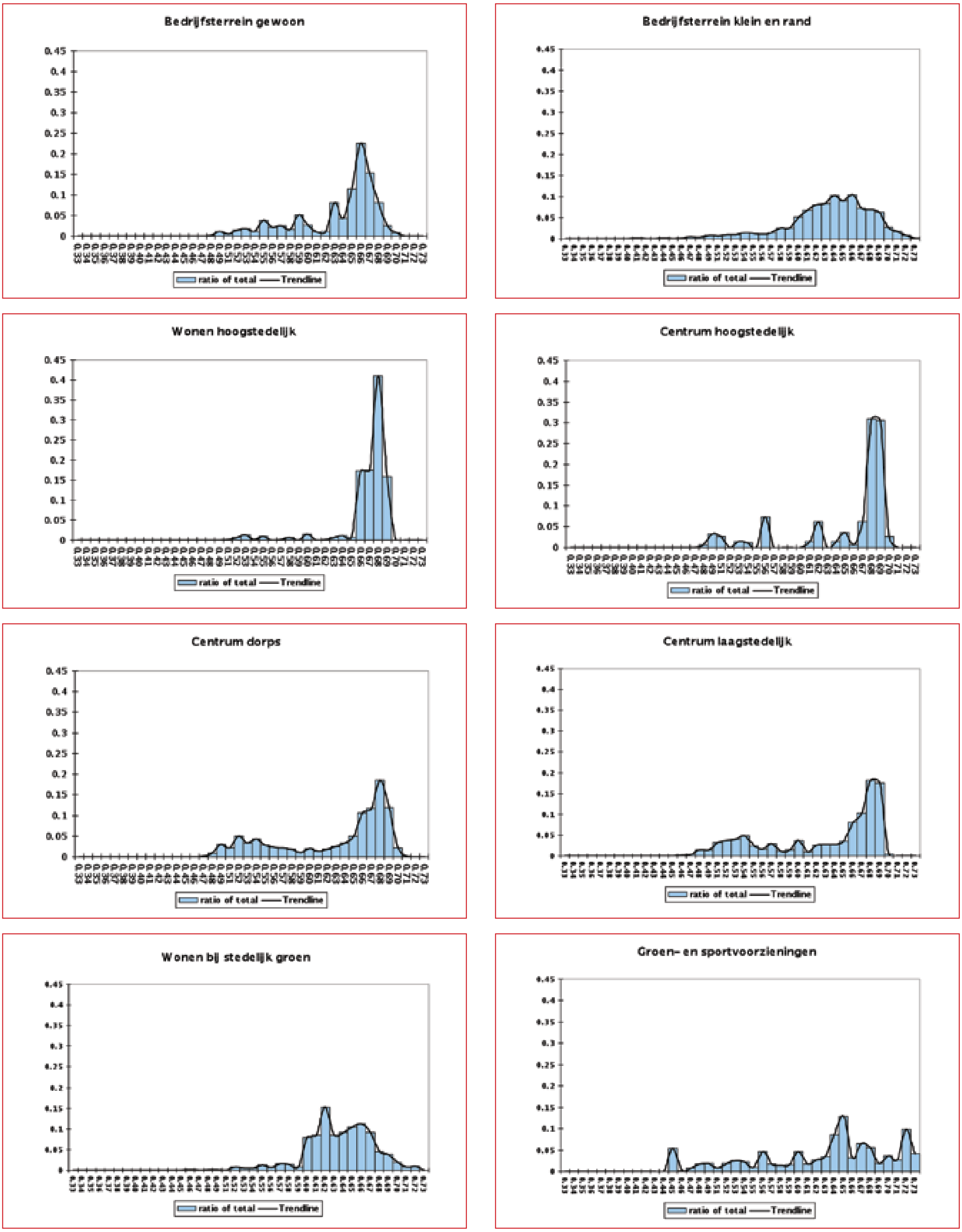


Figure 4.47 Graduality distributions for 8 urban typologies

4.5.3. Sensitivity

The sensitivity of urban functions for temperature variations and the urban heat island effect is not well understood and can therefore not be quantified in this study. As already mentioned in the introduction of the topic in chapter 3, heat stress can have a strong effect on health related issues and even result in casualties. Nevertheless, the sensitivity of the observed outcomes is strongly related to behaviour responses; the application of air-conditioning to the average household might reduce effects. This might have important consequences in relation to energy use and ultimately in climate mitigation. From impact focused perspective though, the main effects of heat stress are expected in the usability of public space. Since most Dutch urban public spaces are not designed for use during extremely hot conditions, pedestrian areas might become unusable during heat waves. This might have a substantially disruptive effect on public life including economic consequences. Most urban centres in which shopping areas are located are not dense enough to provide abundant levels of shade.

There is some indicative information on the effect of higher temperatures on city parks and trees in particular. A rise in the average summer temperature will generally form no obstruction for a normal growth of trees. For indigenous species that are also present in land climates the resilience to drought is enough secured by the genetic variation within the species. This is underlined by the successful existence of these species in the centre of urbanized areas, that naturally have higher temperatures then the peripheral areas. Since temperatures within these urbanized areas are expected to increase significantly related to climate change (as described previously), trees within these areas are likely to suffer heat stress.

In addition, the introduction of 'new' deceases may form a side effect of the expected temperature change and may have an impact on trees as well. The hypothesis is that many decease present in warmer climates than The Netherlands may get a chance to spread as soon as the temperature in The Netherlands rises. It is not known if this hypothesis will ever occur and what the determining factors and processes are. Recent introduction of new deceases can not directly be linked to the effects of climate change.

4.5.4. Intrinsic vulnerability to heat stress

Although the study only touched upon the sensitivity to heat stress, a few final remarks can be made. First of all, the strong relation between downtown, the concentration of cultural and public life and the associated heat stress level are a cause for worry. Because of the intensive use of these areas by pedestrians, these are vulnerable towards longer and stronger heat waves. To some extend this is also valid for village and suburban areas in which life often extends to gardens and public space; the liveability of these areas might be affected negatively. The intrinsic vulnerability of industrial areas is differentiated. Especially since the concentration of employees working outside is limited (the economy centres around the service area), industrial areas might not be a major cause of concern. Even if so, the distribution of heat stress shows a large variability that differs between areas.

4.5.5. Conclusions for heat stress

The observations from the previous paragraphs lead to the following conclusions:

- The overall outcomes show that Dutch cities are hotter than the ambient temperature;
- The heating effect increases when the ambient temperature becomes higher;
- The level of temperature differentiation (variance) becomes larger during higher ambient temperatures;
- The observed extremes (range) become larger during higher ambient temperatures;
- Most urban typologies show a heating effect;
- The spatial distribution of urban heat seems relatively even for all cities;
- Hotspots can be observed in downtown areas but also in village and suburban areas;
- Garden cities are not necessarily cooler.

Especially downtown areas are intrinsically vulnerable to heat stress; public space might become unusable during heat waves which disrupts public life and has potential economic consequences.

5. Adaptation to Climate Effects in Urban Areas

This Chapter describes the results of the adaptation analysis. Paragraph 5.1 presents the results, conclusions and considerations of the analysis of the adaptive potential of cities in The Netherlands. In Paragraph 5.2, an overlay of the analyses of the vulnerability and the adaptive potential will be made to identify 'hotspots' and windows-of-opportunity for free-riding adaptation. Finally, Paragraph 5.3 provides insight in the measures that can be taken to reduce the vulnerability of cities.

5.1. The adaptive potential of cities in the Netherlands

5.1.1. End of lifespan

When calculating the expected end of lifespan (EELS) for buildings, the outcomes show that 43% of the urban housing stock has exceeded the average lifespan. This is shown in Figure 5.1 in which the cumulative ratio of buildings that reached the EELS is displayed as well as the individual addition per year. Since one of the basic foundations for this study is to mainstream adaptation with urban renewal, the 'building agenda' for the coming decades provides an immediate opportunity. Following the outcomes, around 2070 the complete building stock is renewed and the adaptation cycle would be complete. Furthermore, the figure shows that the yearly additions decrease. This suggests that in the coming decades the majority of the urban rede-

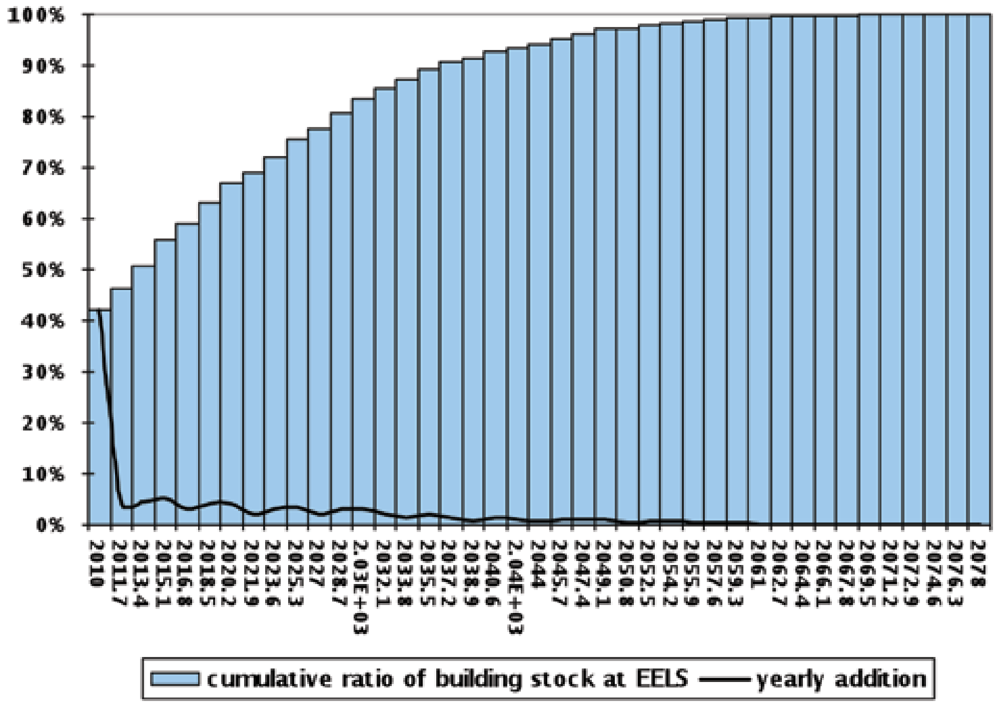


Figure 5.1 The expected End of Lifespan of the total building stock in urban areas in the Netherlands (left) and it spatial distribution (right).

velopment operations would take place. Mainstreaming adaptation would therefore provide benefits at an early stage.

Further analysis on urban typology level changes these figures somewhat. For downtown residential areas the current ratio of buildings at the EELS adds up to about 75%, while for rural residential neighbourhoods (within the urban extent) this value only reaches about 18%. Industrial and office areas score relatively average; 37% of these areas has currently reached the EELS, while for peripheral industrial areas this average drops to 34%. In general the outcomes show that the majority building stock in Dutch downtown areas seems to be outdated, while for other areas significant levels of differentiation are found.

These outcomes can be further tested by investigating the spatial distribution of the EELS. The outcomes are shown in Figure 5.2.

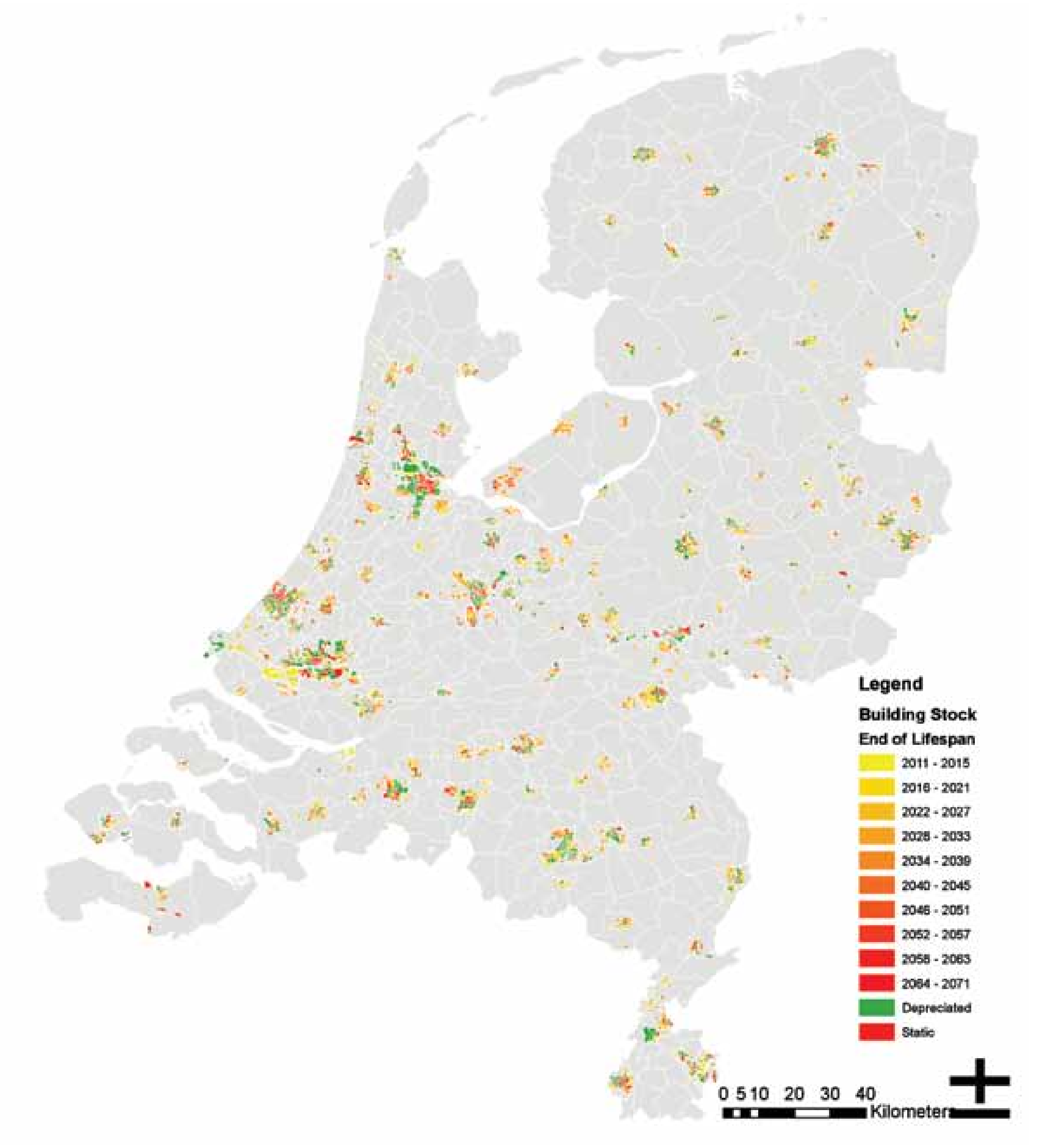


Figure 5.2 The spatial distribution of the expected End of Lifespan.

An additional notion, displayed in Figure 5.2 is that of a ‘static’ EELS. Static EELS identify areas dominated by significant amounts of historical buildings or other features not expected to be replaced. This adds an additional constraint to the assumption of mainstreaming. An observation that confirms intuition, is the relative late EELS for new towns like Almere, Lelystad and Nieuwegein. These cities originated from the early 1980s with a majority of the building stock dating from recent years. A similar pattern can be observed for many suburban areas located in the peripheries of the cities.

The question that remains is if the calculations for the EELS are actually reflecting reality; as many buildings are upgraded over time due to substantial maintenance cycles. This extends their EELS beyond the projected scope. Furthermore, the outcomes do not take political and business decisions or the projected cultural value into account. To put this in perspective, about 7% of the total building stock in The Netherlands is older than 1920. A significant part of this can be considered as heritage that is unlikely to be replaced by new buildings or other functions. Furthermore, also residential areas from the 1930s have gained a large popularity and market value. This means that their actual lifespan is likely to exceed the calculated EELS. As a result, it would be incorrect to assume that the actual lifespan of buildings equals the results of this study; most likely, the projected EELS are stretched out further by years to decades.

To investigate the variability further within the EELS, analysis has been performed on the observed ranges. Figure 5.3 shows the average life cycle period of the total building stock of urban areas in The Netherlands (left), commercial areas, (centre) and commercial areas (right). The distribution of the average lifecycle of the total building stock of urban areas in The Netherlands is more or less normally distributed, with an average value around 50 years. This means that the average life cycle period of all individual buildings, according to Ritsema, Van Eck, et al (2009), and categorised neighbourhoods is 50 years. However, between buildings in one neighbourhood a large variability could exist. Most residential environments show a normal distribution that indicates a clear relation between urban typology and the average life cycle period.

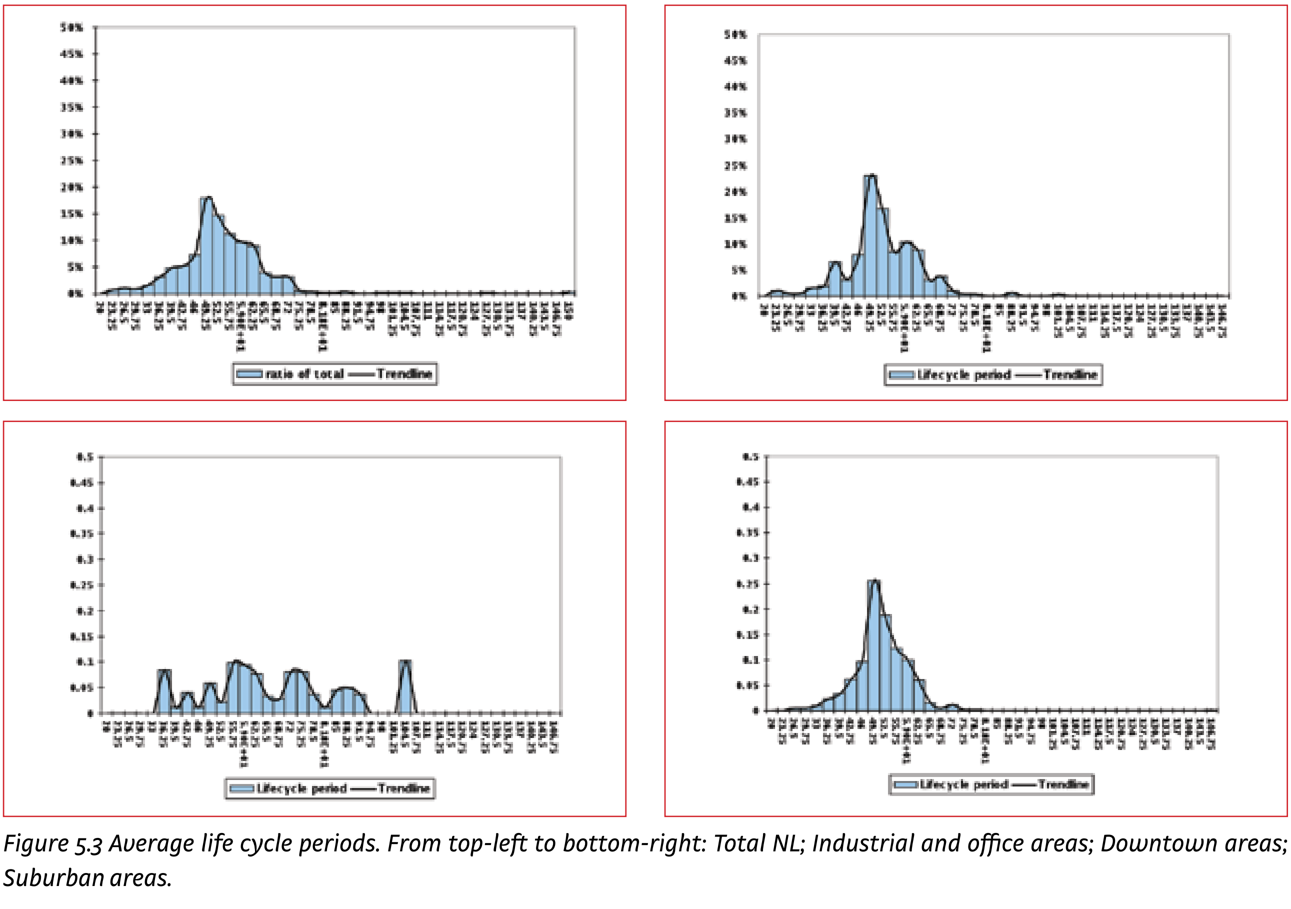


Figure 5.3 Average life cycle periods. From top-left to bottom-right: Total NL; Industrial and office areas; Downtown areas; Suburban areas.

Figure 5.3 clearly illustrates the variability within and between the EELS distributions for different urban typologies. This is illustrated already in the distribution for the whole of The Netherlands. The range for 95% confidence levels is between 20 and 72 years. While this range is almost similar for industrial and office areas, extremes are found for downtown areas ranging between 38 and 104 years. For suburban areas, on the other hand only a limited variability is found. Here the range covers only 30 years (with a range from 40 to 70 years). One of the main reasons for these differences is the differentiation found within the urban areas. Suburban areas for instance are often built during massive development leaps often covering hundreds or even thousands of similar buildings. Within the downtown areas on the other hand, a process of small redevelopment has been taken place over the last century. Individual buildings have been demolished and were replaces by different functions and building types with possibly a lower lifespan. The resulting differentiation creates a much larger variability and makes it more difficult for predictions. Furthermore, there is a more technical reason for the observed variability. Since the extent of the urban typologies is relatively coarse compared to the urban data used for analysis, the boundaries between different typologies are relatively imprecise. This results in misclassification and some loss of accuracy. Although a thorough sensitivity analysis has not been performed, initial tests show that the amount of misclassifications is limited. We expect inaccuracies of between 5% and 10%, which are propagated within the presented distributions.

Although there are certainly limitations to this method, it does lead to a very important conclusion for developing adaptation strategies: If immediate opportunities linking climate proofing-measures with urban redevelopment are not being taken, there will on average not be another chance for 'free' adaptation in the next decades. In case adaptation is needed anyway during this period, retrofitting needs to be applied. This means that existing building stock needs to be modified which might result in substantial additional costs. Therefore, policy/legislation should require no-regret measures and abandonment of non-robust practice (such as the practice of building site preparation, new commercial districts etc) (see next Section).

5.1.2. The adaptive potential as input for adaptation strategies

How can we use end of lifespan and life cycle periods in adaptation strategies? The traditional way of adaptation is purely vulnerability driven. Measures are implemented independently of autonomous development and are organized and executed as a virtually response system. Zevenbergen et al (2008), argue that climate change adaptation might be considerable more cost efficient when mainstreaming measures into the urban renewal cycle. This would require extension of the current planning horizon in order to be able to realise timely responses.

As covered in chapter 3 on methodology, the vulnerability is defined as the combination intrinsic vulnerability and the adaptive capacity. Since this assessment is made for four different topics, a method should be applied to combine the outcomes. Generally, some kind of multi-criteria evaluation would be applied to weigh the different components against each other. Since the study covers the complete urban extent of The Netherlands, an extensive process should be initiated to involve local, regional and national stakeholders in evaluating the intrinsic vulnerabilities per topic. Ultimately, the evaluation would still be arbitrary from the reader's perspective. Furthermore, since the intrinsic vulnerability component is defined mainly through a qualitative assessment of exposure, the outcomes are mainly indicators for a much more thorough traditional vulnerability assessment in which exposure is combined with a quantitative assessment of hazard and sensitivity. Therefore, the chosen method for this study is to simply superimpose the outcomes for the different climate topics and analyse the resulting ranking. The aggregate results are presented in Figure 5.4 (pie chart) and Figure 5.5 (spatial distribution).

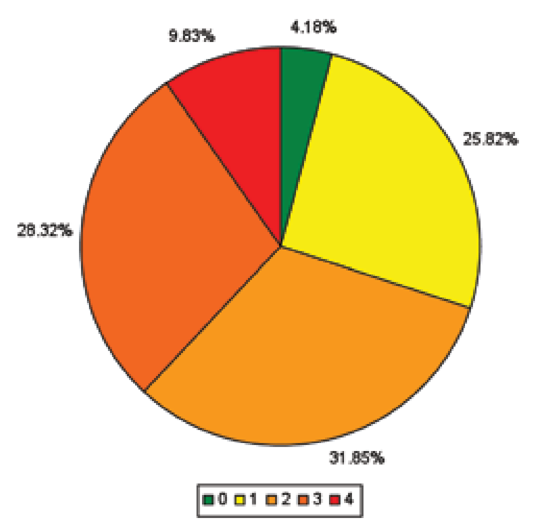


Figure 5.4 Ratios of the superposition of intrinsic vulnerabilities for the complete urban extent in The Netherlands. A value of 0 indicates that the area is not susceptible for any of the 4 topics.

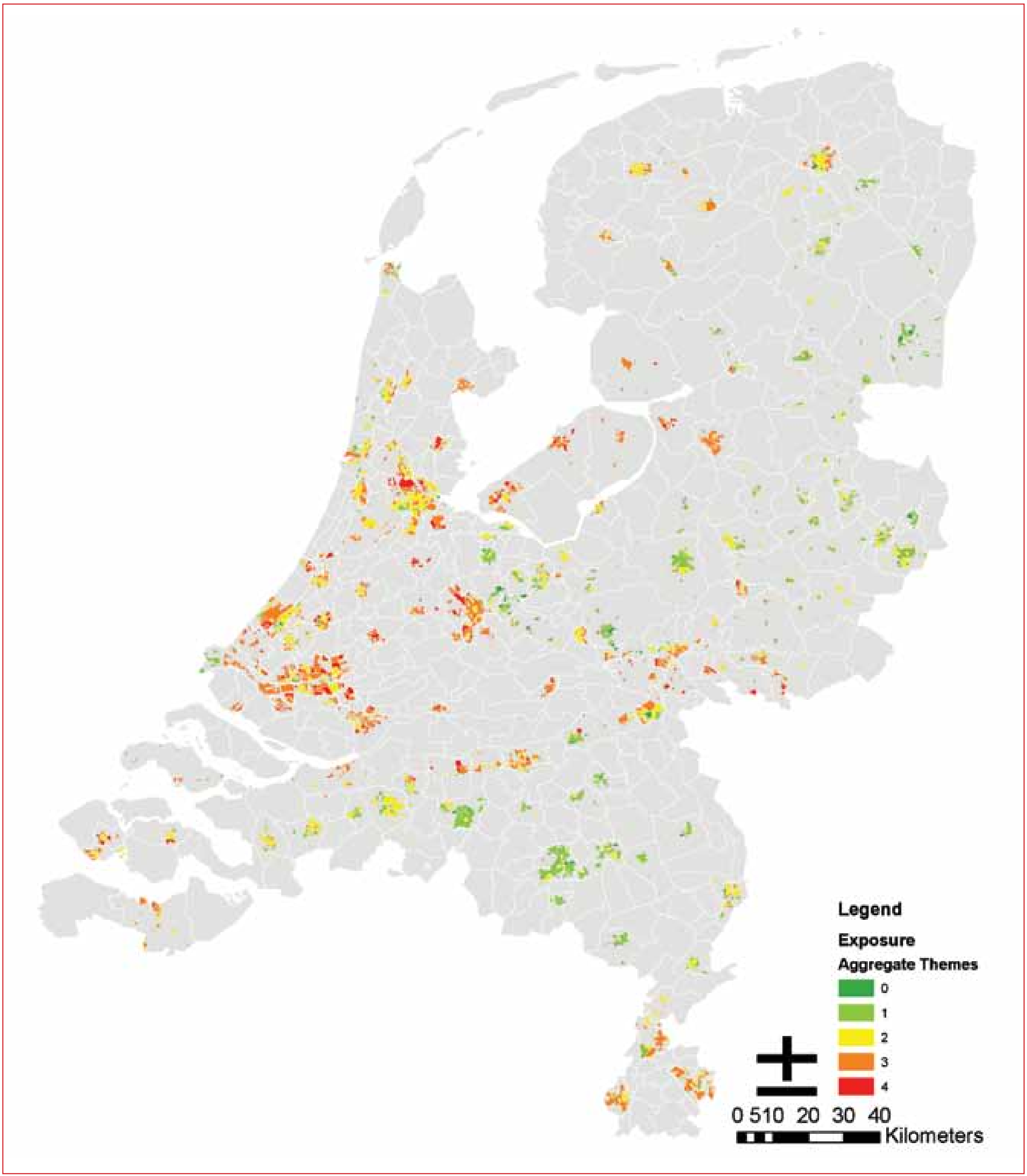


Figure 5.5 Spatial distribution of the superposition of intrinsic vulnerabilities for the complete urban extent in The Netherlands. A value of 0 indicates that the area is not susceptible for any of the 4 topics.

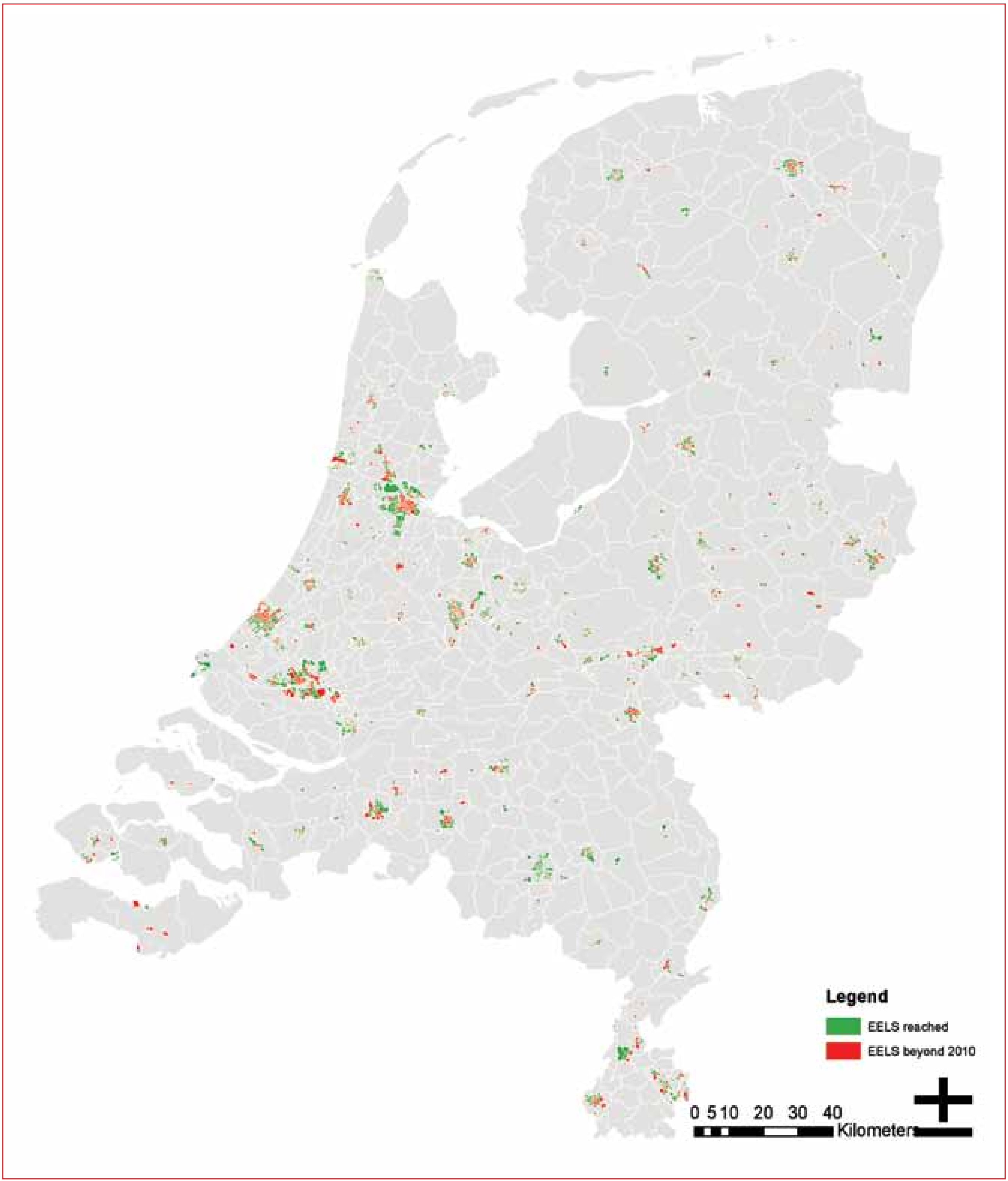


Figure 5.6 Buildings reaching the EELS during or before 2010

From the two figures it can be concluded that about 96% of the Dutch urban extent is susceptible to one or more climate hazards. The distribution between susceptibilities for a single, 2 or 3 climate hazards is almost equal. About 10% of the urban areas is susceptible to all 4 climate hazards. The spatial distributions show that a significant amount of cities located in the eastern (Gelderland, Overijssel), southern (Noord-Brabant) and northern (Drenthe) provinces of The Netherlands are ranking lower. This can be explained to some extent by the limited susceptibilities of these cities to fluvial flooding, water nuisance and drought. Since most of these cities are located outside of the polder areas and floodplains of major rivers, they are safeguarded against 3 of the 4 studied climate hazards.

The second component for calculating the vulnerability is the adaptive potential. This component is dependent on the set horizon, since it expresses the building stock reaching the EELS at some moment in time. The spatial distribution of the EELS with a chosen horizon of 2020 is shown in figure 5.6. These outcomes include the so-called ‘static’ environments in which historic buildings and other structures that are difficult to adapt, dominate the area. This limits the urban extent reaching the EELS to a 39% in 2020 (compare to figure 5.1).

Finally, the outcomes from Figure 5.5 and Figure 5.6 are superimposed to obtain the actual vulnerability with a horizon of 2010 and 2020. These outcomes are presented as ratios in Figure 5.7.

Figure 5.7 clearly shows the impact of a full mainstreaming operation. If buildings and other areas reaching the EELS were actually replaced, a substantial reduction in ‘intrinsic’ vulnerability’ could be realized. While currently only about 4% of the urban extent is safeguarded against the studied climate hazards (see figure 5.4), a level of 40% could be reached right now. This level would increase to 61% in 2020. Intrinsic vulnerabilities for one or more climate hazards would be reduced to almost half, while the ratio areas most vulnerable areas (‘intrinsic’ exposure = 4) remains constant.

Since the EELS is always determined by application of some chosen horizon, the resulting adaptation process is dynamic. The method applied for the horizon of 2020 has therefore been extended to a much larger range for which the results are presented in Figure 5.8.

The results in Figure 5.8 show how fast the aggregate exposure to climate effects can be reduced by only using opportunities of urban renewal. Implementing adaptation measures in the total building stock that has reached the end of lifespan could reduce the exposure significantly. Note that the illustration uses the assumption that adaptation measures have the ability to completely marginalize the intrinsic vulnerability. The current EELS gives an immediate opportunity for climate proofing 39% of the existing urban area. By 2050, 92% could be climate proofed under this scenario. However, in reality adaptation measures can never reduce the exposure to zero and not all urban areas reaching their EELSs will be redeveloped to climate proof urban areas. This means that Figure 5.5 gives a rather overestimated impression of the rate and its effects of linking adaptation to ongoing urban renewal. Still, it can be concluded that the adaptive potential of urban areas offers the opportunities to climate proof a major share of the existing building stock over the next 50 years.

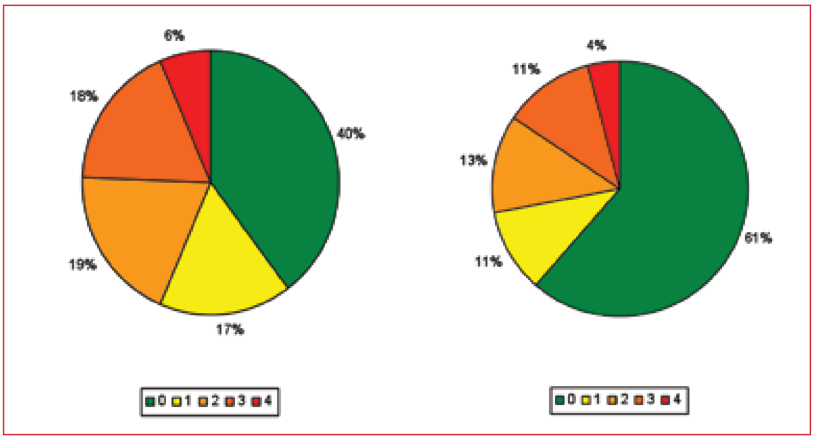


Figure 5.7 Overlay of exposure and adaptive potential of urban areas for 2010 (left) and 2020 (right).

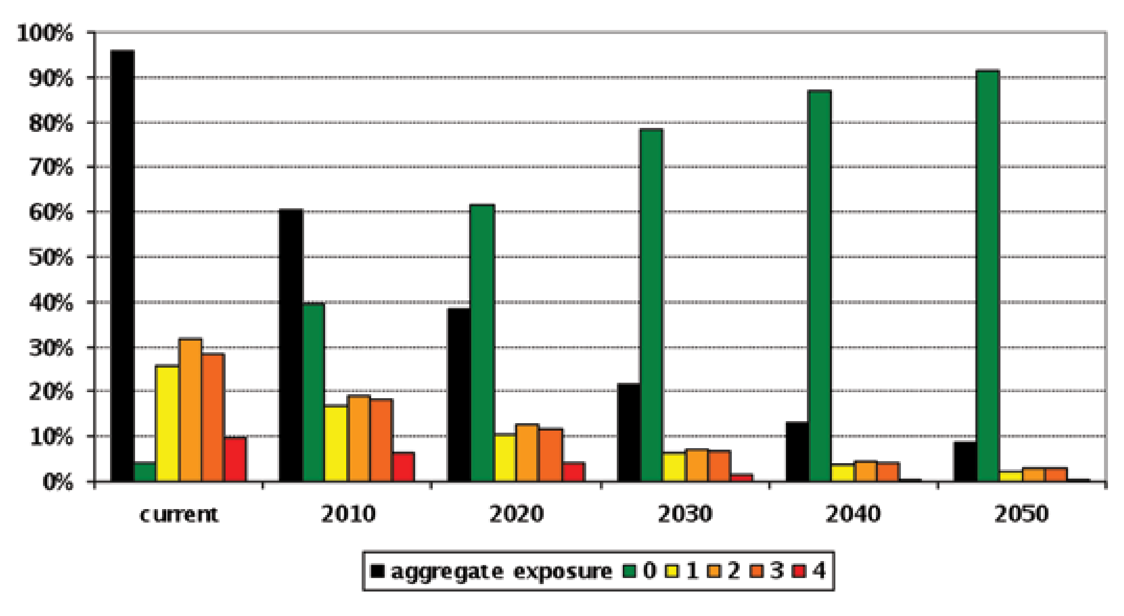


Figure 5.8 Windows-of opportunity for linking adaptation with urban renewal over time

As concluded before, it could take approximately 50 years before another opportunity will rise to link adaptation with urban renewal. Active adaptation is recommended in the areas in which it is believed that the current or near future vulnerability is unacceptable and no timely opportunity rises to link adaptation with urban renewal. For these areas, depending on the local conditions, adaptation can be prioritized by the degree of vulnerability or by the amount of vulnerabilities (see Chapter 4).

The approach that is presented here could probably also be used to assess effectiveness of linking mitigation with urban renewal. CO_2 emissions of old and new building types could be used as an input in renewal models. This could result in quantification of mitigation efforts in buildings for The Netherlands as a whole. It is recommended to elaborate on this aspect in a follow up of this project in order to quantify the effect of linking mitigation to autonomous urban dynamics.

The approach that is presented here is new and still leaves many questions. For example, how do we assess whether the adaptive potential is sufficient for developing timely adaptation strategies in the face of climate change? And, to what standards should adaptation measures be included in urban renewal? Real option analysis that uses scenarios for climate change and urban dynamics as an input could partly fill this gap (see for example Gersonius et al, 2010), but this will not take away the normative discussion to determine what levels of 'climate proofness' are acceptable and desired. As we will see in the following Section, there are ways of dealing with this aspect.

5.1.3. Conclusions

Based on the previous insights, a set of conclusions can be drawn:

- Currently about 43% of the building stock has reached the EELS;
- The EELS shows a significant amount of variability within and between urban typologies. This especially holds for downtown areas;
- Of the complete urban extent, only 4% is not exposed to any of the studied climate hazards;
- Cities located in polder areas show the highest levels of 'intrinsic' vulnerability;
- Mainstreaming adaptation with urban renewal could lead to a significant vulnerability reduction;
- If areas reaching the EELS would actually be redeveloped, by 2050, 92% of Dutch urban extent would be protected against the investigated climate hazards. Method not comprehensive;
- The produced outcomes are sensitive to perturbations for a range a variables.

5.2. Adaptation measures

5.2.1. Selecting adaptation measures

Based on the work of Van Drunen and Lasage (2007), Van de Ven et al (2009) and Rahola et al (2009) a list of 87 different adaptation measures has been compiled (see Appendix B). This list does not attempt to be exhaustive, but aims to give insight in the possible technical responses for adaptation to climate change. Figure 5.9 shows that most measures are identified within the water domain while the portfolio for measures reducing the impacts of heat stress is less extensive at this stage.

Drought measures have a significant overlap with water nuisance measures, which implies that these measures mitigate vulnerability to drought *and* water nuisance. To a lesser degree, the same holds for water nuisance and flooding measures. Furthermore, some measures reduce vulnerability to heat stress and water nuisance at the same time. Investigation of the portfolio of adaptation measures also reveals that synergy is possible between adaptation and mitigation measures. Heat measures in particular have the potential for synergy with mitigation strategies. From this, it can be concluded that there is in theory a potential for mitigating multiple vulnerabilities and realising adaptation and mitigation at the same time. However, this does not express anything about the effectiveness of such combinations, because two separate measures could have a larger combined effect than one measure that addresses two vulnerabilities. Local conditions determine whether these combinations offer indeed desired responses in urban design. A rough assessment of the physical applicability in different urban typologies made clear that the choice for measures is in theory only marginally restricted by the urban typology in which it has to be realised. In contrast, at this point there is not sufficient knowledge about favourable matches between adaptation measures and urban typologies. It is recommended to explore this further in the future.

Figure 5.10 shows the regret potential of adaptation measures. A distinction is made between measures that increase threshold and measures that increase coping capacity. Around 50% of all identified adaptation measures to water nuisance, drought and heat have a no-regret potential. The regret potential of most measures against flooding is higher, because they are significantly more expensive. From the diagram of regret potential for measures that increase coping capacity it can be concluded that there are potentially many ways to increase the coping capacity of cities without future regret. This holds true for all vulnerabilities. Summarising, the conclusion could be drawn that there are many known possibilities to realise no-regret adaptation measures against all types of flooding, drought and heat. When implemented adequately, these measures have no additional cost in comparison to conventional solutions and offer no adverse effects on the short and long term. Therefore, they should be implemented when the opportunity emerges. This requires guidelines and other facilitating institutional arrangements (see Chapter 6).

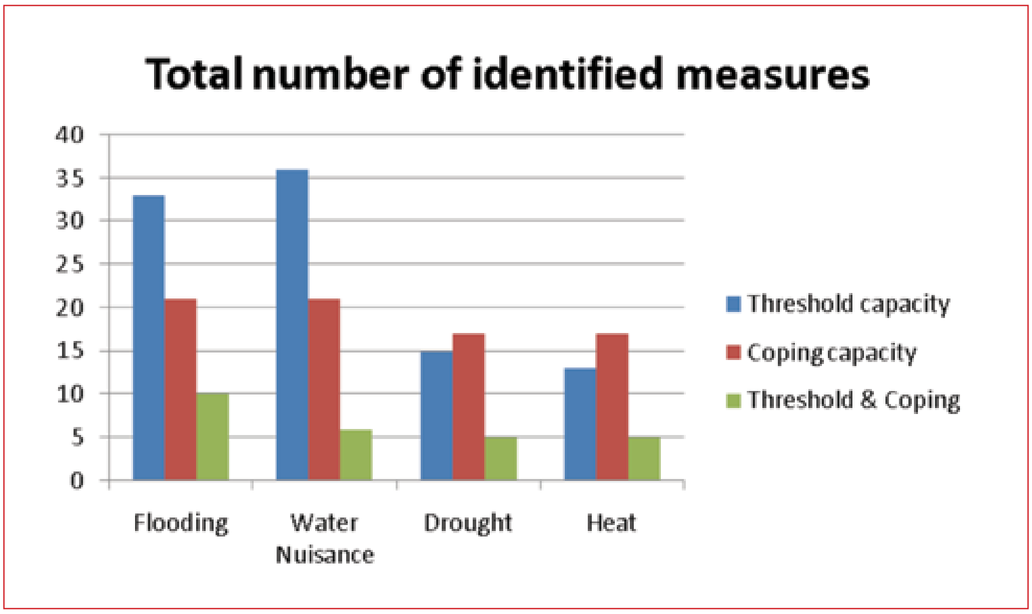
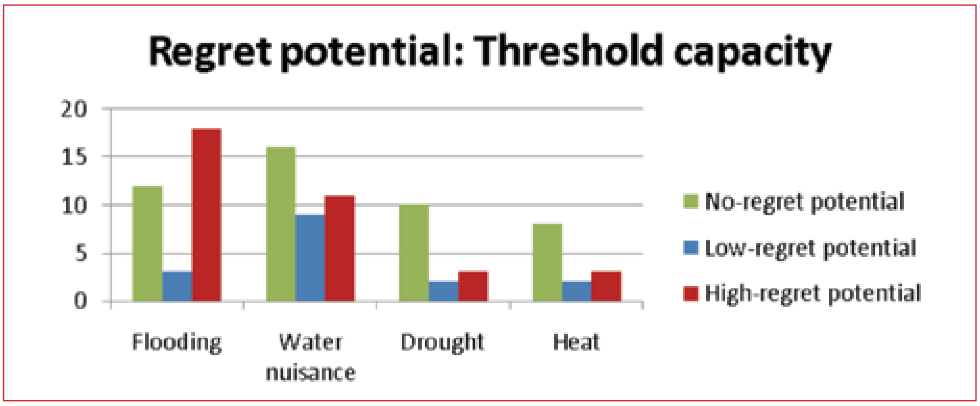


Figure 5.9 Portfolio of identified adaptation measures



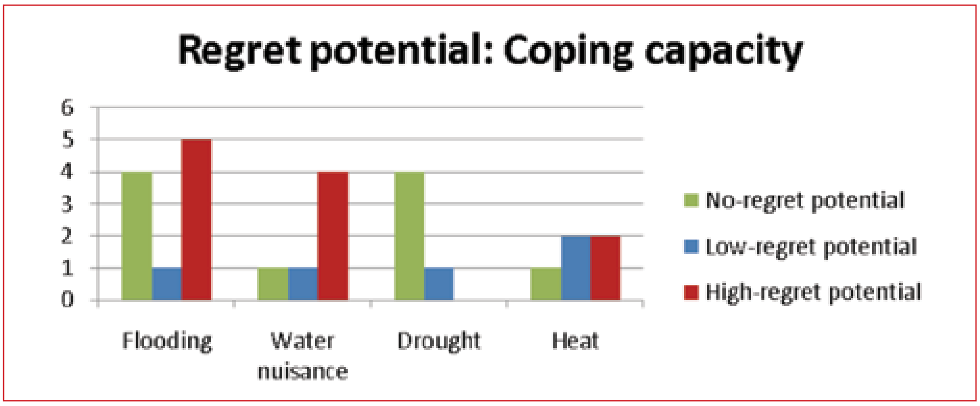


Figure 5.10 Regret potential of adaptation measures, based on adverse effects and potential cost increase.

A wide range of actors is involved in adaptation to climate change in urban areas. In this study stakeholders are categorised in national, regional and local governments, water boards, the private sector and the community. Based on the list of measures that has been established, Figure 5.11 shows the number of available measures for different stakeholders. Here, available measures are measures that can directly be allocated by a particular stakeholder group. In general, it could be concluded that a wide range of stakeholders could be involved with adaptation. However, regional governments (provinces) have limited ways of directly influencing realization of specific adaptation measures. Also, the conclusion can be drawn that the character of the respective 'intrinsic' vulnerabilities (see Chapter 4) corresponds with the size of the portfolio of available measures of stakeholders at different scale levels. For flooding (water safety), the national government, waterboards and local government have the largest portfolio of possible measures available. For water nuisance and drought this shifts towards a lower scale level: waterboards and local governments have the most available measures. At present, it could be said that heat is mostly a local issue, since nearly all identified measures are available for local governments, the private sector or the community. Although it is analysed here that stakeholders in the public and private sector both have a portfolio of measures available to address climate change, this does not say anything about the responsibility of stakeholders for adaptation. In The Netherlands, the private sector and the community have little responsibility for adaptation. Adaptation falls therefore for the greater part in the public domain. This is not only the case for active adaptation, but also for opportunistic adaptation (sees Chapter 3).

From this qualitative analysis it can be concluded that depending on the local conditions, all urban typologies could be 'climate proofed' by use of existing technologies. In Chapter 4 it was concluded that it is not possible to distinguish a clear relation between exposure to climate hazards and urban typologies in different cities in The Netherlands. Also, it is impossible to make quantitative statements about the effectiveness and the cost-benefit ratio of measures. Because of this, it is not possible to solve the 'adaptation problem' with a series of, let us say, five easy rules for giving direction to adaptation in practice. Adaptation needs to be tailored to the local conditions.

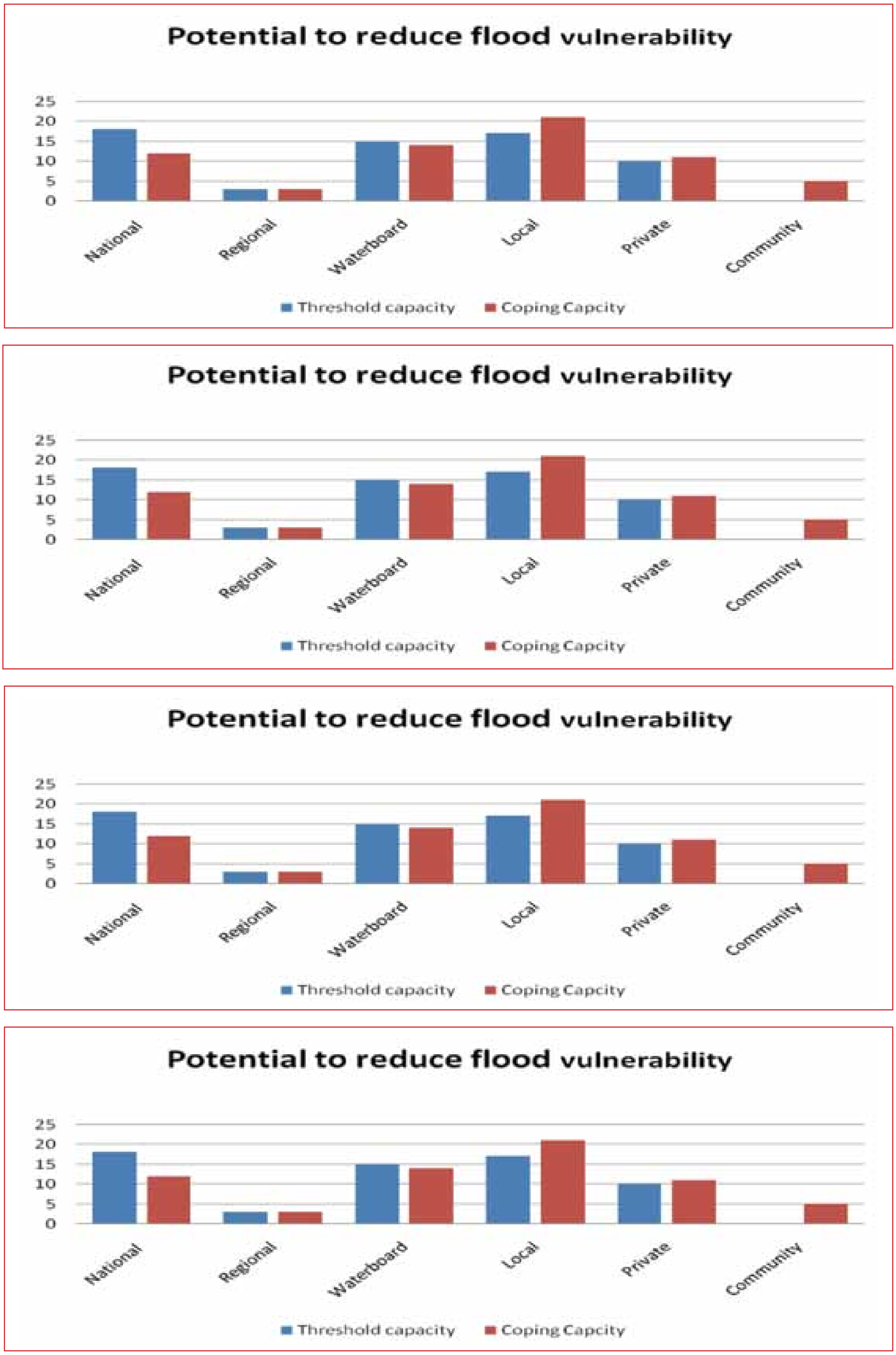


Figure 5.11 Potential available adaptation measures for different stakeholder groups

Section 5.2 ended with the question what levels of 'climate proofness' are acceptable and desired. This question stems from an adaptation approach in which vulnerability is the starting point for adaptation. This is logical, but maybe not the best way to go in order to give guidance on adaptation to policy and practice. Limits to predictability, difficulties to deal with complexity and incapability to quantitatively assess the sensitivity of cities and the effectiveness of measures make operationalisation of vulnerability based approaches in practice extremely difficult. Using the potential of adaptation as a starting point may be a good alternative. As we have concluded before, many technical possibilities exist for no-regret measures for all hazards that can be applicable in all urban typologies. If implementation of these measures becomes the standard, big steps can be made in putting adaptation in place. However, this may require an extensive cultural change.

5.2.2. Conclusions

Based on the previous insights, a set of conclusions can be drawn:

Selection of adaptation measures

- Selection of adaptation measures requires knowledge of local design properties.
- There is insufficient knowledge about effectiveness and cost-benefit ratio of measures. However, the question is whether this will ever be clear, because of complex dynamics of urban systems.
- Physical applicability in different urban typologies is not a problem.

Maximise the no-regret zone

- No-regret measures should be implemented when the opportunity emerges.
- Around 50% of all identified adaptation measures to water nuisance, drought and heat have a no-regret potential. For flooding costs are for most identified measures significantly higher so that regret potential is higher as well.
- Many ways to increase coping capacity without potential of future regret. (all categories).

Maximise linking with mitigation strategies

- Awareness about mitigation is larger. Willingness to take action possibly as well. Therefore, mitigation could open opportunities for adaptation.
- Adaptation to heat offers many synergy opportunities with mitigation.

Stakeholder involvement

- A wide range of actors is involved with climate adaptation. Regional governments (Provinces) have limited ways of directly influencing realization of specific adaptation measures.
- Flooding (water safety): national, local government, waterboards have the largest portfolio of possible measures available to reduce vulnerability for flooding.
- Water Nuisance and Drought: predominantly Waterboard and local government.
- Heat: local, private and community.

6. Coupling Adaptation with Existing Policies and Instruments

6.1. Introduction

This chapter inventories existing policy and instruments related to climate vulnerability and adaptation. The analysis of climate vulnerability and adaptivity of urban areas in The Netherlands (chapter 4 and 5) should lead to policy recommendations (Chapter 7.2). Those policy recommendations will have to take existing policy into account. Either to comply with existing policies in a restrictive sense, or to couple recommendations with existing policies and instruments to facilitate implementation. The relationship between the different parts is represented in Figure 6.1 below.

6.2. Methodology

The inventory started with a classification of policy and instruments per related policy fields and per spatial scale level. Firstly, the following policy fields are distinguished to structure the inventory process:

– Spatial planning, related to adaptivity
– Water Management, related to vulnerability, and
– Heat stress, related to vulnerability.

Furthermore relevant policy and instruments are categorized per spatial scale level:
– National (including international policy implemented via national policy)
– Regional
– Local.

A wide range of policy documents in these categories have been consulted based on desk research and expert indications. The national adaptation strategy (VROM, 2007) provided an extensive overview of (possible) initiatives to adapt spatial planning for the benefit of safety, living environment, ecology and economy.
A selection of relevant initiatives is made from this overview, and where relevant completed with other initiatives. Finally, in more depth, policies have been inventoried for specific urban typologies. Urban typologies for which sig-

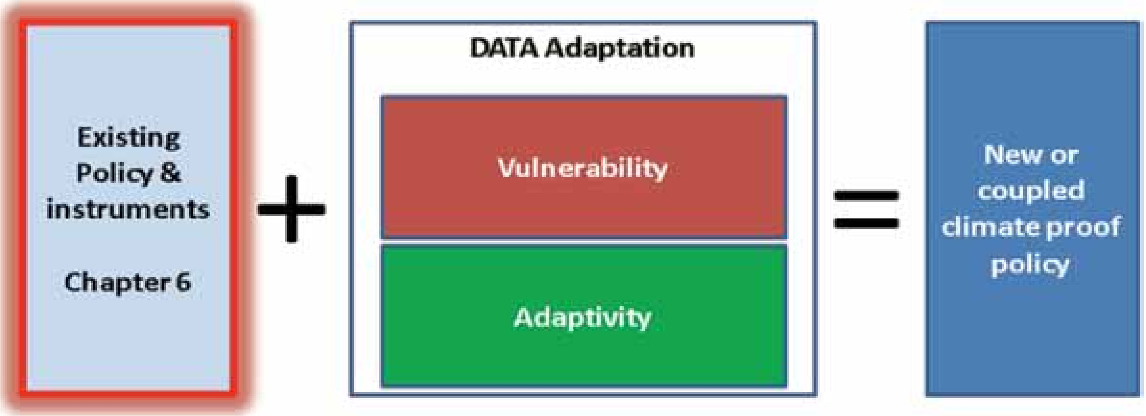


Figure 6.1 Coupling climate adaptation recommendations from the vulnerability and adaptivity analysis to existing policies and instruments

nificant conclusions have been drawn from the vulnerability or adaptivity analysis. There, coupling opportunities with existing policies and instruments seem most relevant or urgent.

6.3. Existing policy and instruments

The most relevant policies and instruments are summed up per scale level, which logically correspond to government agencies operating at that level. This inventory is not exhaustive, but provides a starting point for coupling policy recommendations, following from the climate vulnerability and adaptivity analysis, to existing policy and instruments.

6.3.1. International

In April 2009, the European Commission presented a policy paper known as the White Paper which presents the framework for adaptation measures and policies to reduce the European Union's vulnerability to the impacts of climate change under the title "White paper on adapting to climate change" (Commission of the European Communities, 2009). Its implementation in The Netherlands is an opportunity to include this reports' policy recommendations. For flood vulnerability, the EU adopted the Floods Directive to be implemented in The Netherlands before 2015. Here, flood vulnerability can be addressed.

6.3.2. National

National Spatial Strategy

The national spatial policy is mostly set by the Ministry of Housing, Spatial Planning and the Environment (VROM). Their pivotal policy product is the National Spatial Strategy that sets out policy up to the year 2020 (VROM et al, 2006). The document includes an implementing agenda that is amended from time to time. Related to this Spatial Strategy, the ministry has set and can revise the Spatial Planning Act and land usage policy. The ministry states that ¨The National Spatial Strategy has shifted the emphasis from "imposing restrictions" to "promoting developments". In the framework of this research this would translate to national policy that stimulates climate proofing per development and for a particular area in a 'development planning' process. The ministry can do this via its implementing agenda which corresponds to the National Spatial Strategy and includes central government's investment priorities, the effects of policy on local planning and zoning schemes and the use of implementing instruments. Here, many relevant investment vehicles and planning instruments can be used for climate adaptation. Finally, national spatial policy advocates a layer approach for spatial planning, as also recommended by Priemus (2007). Climate adaptation should be considered per layer. Especially in the substratum, that includes water system, soil, etc, many opportunities for coupling measures can become apparent. Adaptation policy can provide guidance on how to consider and implement adaptation in each layer.

National Adaptation Strategy

Specifically for Adaptation the national government started the National Program Adaptation Space and Climate (ARK) (VROM et al, 2007). This is a collaboration between the ministries of Housing, Spatial Planning and the Environment (VROM), Transport, Public Works and Water Management (V&W), Agriculture (LNV) and Economic Affairs (EZ) and the associations for provinces, municipalities and water boards. This collaboration led to a National Adaptation Strategy.

This strategy also highlights the need for climate proofing per development and for a particular area in a 'development planning' process ('maatwerk'). The national strategy's starting points are very much in line with this study. It stated that the spatial planning should become increasingly climate proof as:

- Spatial investments structure and steer and thus measures are needed to maintain flexibility for future spatial adaptation.
- Smart spatial investments now can avoid high cost adaptation in the future.
- Increasing investments enhance vulnerability and thus vulnerability reducing measures are necessary.
- Climate change can develop at a different pace, slower or faster, than foreseen.

The National Adaptation Strategy stresses resistance, resilience and adaptivity potential as key criteria for climate proof spatial planning. That, in turn, comprises of zoning (where to develop), spatial design and design of buildings (how to develop).

Work together, live together

The policy programme 'work together, live together' (Ministerie van Algemene Zaken, 2007) states climate proof spatial planning as one of six main objectives under pillar 3. This programme announces a research into the vulnerability of the Main Spatial Structure (Ruimtelijke Hoofdstructuur) and the development of a decision making framework for zoning and development. The National Spatial Strategy provides budget for integrated climate proof development of areas. The Urgency Programme Randstad is also directed to making the Western part of The Netherlands more climate proof.

In addition to these national policies, the following national policy programmes are relevant to mention:

- The National Water plan (V&W, 2008) and the water safety policy (V&W, 2006) use a risk based approach. Thus these policies provide the basis to include measures to reduce vulnerability to drought, water nuisance and water safety.
- The revised national water agreement (Nationaal Bestuursakkoord Water, V&W et al, 2003) explicitly stressed the need to deliver climate proof water systems. This provides a framework for climate proof investments and maintenance of water systems.
- A revision of the policy programmes and investment budgets for urban renewal and rural areas is foreseen which could facilitate the incorporation of climate proof objectives and approaches.
- Existing decision making frameworks and instruments such as societal cost-benefit analysis (MKBA) and research-effects-infrastructures (OEI) can be adapted in 2009 and could thus include climate proofing.

6.3.3. Regional

As opposed to the national level, at regional level development planning is actually implemented. Think of: change of functions, integration of functions, functions following water levels, adjusting the spatial structure. The national adaptation strategy indicates the following opportunities to couple adaptation policy at regional level:

- Area development programmes should address climate vulnerability and specific hotspot projects are selected.
- Investments in regional water systems (National agreement water (NBW) and Water Framework Directive (KRW) and investment in rural and urban areas (ILG and ISV) should consider climate scenarios. Hence, regional spatial plans (structuurvisies) should be climate proof, based on so-called climate atlases.
- Specific pilot projects are to be selected in areas of several municipalities and water boards.

6.3.4. Local

Development projects, including change of functions, could be adopted in local spatial plans and could obtain several (e.g. building) permits. Here the climate proofness of developments could be considered. The following opportunities are stressed at local level:

- Local spatial plans and related permits.
- The same goes for Environmental Effects Reports (MER) and Water tests.
- It can be stimulated that urban renewal funded by ISV considers water nuisance and heat stress, as well as the creation of green-blue corridors and recreational areas around urban areas.
- Urban (municipal) water plans and sewage plans are other local policies that could consider climate change more explicitly.
- The new law on land exploitation (Nieuwe Wet Grondexploitatie), makes it possible to recover possible adaptation costs.

Briefly analyzing the above, one observes that in The Netherlands at all scale levels policy and instruments exist to implement climate adaptation policy. In fact, the national adaptation strategy already highlights policy initiatives that use these instruments to address climate change or otherwise proposes policies at various scale levels. However, hardly any reference is made to policy that addresses heat stress. Either climate adaptation is mentioned in general, or specific for water nuisance and flood risk. National policy that stimulates or provides guidance to reduce heat stress seems lacking. Again, the implementation of heat vulnerability reducing strategies and measures is expected to be local and area specific.

6.4. Coupling urban adaptation policy with existing policy and instruments.

In the previous section a selection of existing (or foreseen) policies and instruments are listed that could facilitate policy development and implementation to climate proof urban areas in The Netherlands.

The overview, logically uses the existing institutional context of administrations and instruments as a starting point. However, the analysis of vulnerability and adaptive potential (chapters 4 and 5) was conducted for all Dutch urban areas, independently of the regime or scale levels. Differences in both indicators were highlighted for different standard urban typologies. National policy or guidance might be recommended per urban typology where patterns have become apparent and possibilities to facilitate specific actions are signalled. Deliberately the verb 'facilitate' is used again as implementation requires development planning for a particular area, which the national adaptation strategy already (in our view, correctly) highlights.

Other related policies are inventoried based on the initial identification of vulnerability or adaptive potential patterns per urban typology. Additionally specific policies for urban development phenomena are added. After a brief desk research, a selection of policies are listed for:

- Industrial areas;
- Cultural heritage;
- Social urban renewal (e.g. so-called 'Prachtwijken');
- Urban shrinkage.

Hence the initial matrix can be extended with an additional dimension per urban typology or phenomenon.

6.4.1. Industrial areas

No concrete policy documents were found, but the 'Advice taskforce industrial areas' (VROM, 2009) and 'Inventory working location in The Netherlands' (IBIS, 2009) provide the following policy recommendations:

- Stimulate the use of existing industrial areas and accelerate their redevelopment or regeneration.
- Improve the quality of industrial areas, both existing and new. These recommendations point towards a high adaptive potential. And if and when these recommendations are adopted into policy the specific climate vulnerability of these areas can be taken into account.

6.4.2. Cultural heritage

No related policy was found via the Ministry of Housing, Spatial Planning and the Environment (VROM), nor via the ministry of Education, Culture and Science. Based on the recommendations on cultural heritage specific coupling opportunities need to be further explored.

6.4.3. Social urban renewal

Policy objectives are mainly social: living, working, education and growing up, integration and safety. References to physical measures stress objectives on the quality of the living environment through the use of green areas, also used for social objectives. Related funding comes from ISV, 'Grote Steden Beleid' and 'Groen in de Stad'. Climate proofness could be added to objectives related to the living environment and its consideration stimulated via these funding instruments. As social objectives seem leading for urban renewal, adaptation measures should seek coupling with social objectives to facilitate implementation and access funding.

6.4.4. Urban shrinkage

Growing political attention is observed for decreased population and urban shrinkage in certain Dutch cities. Policy objectives are defined related to spatial policy, housing, commerce and green and quantitative and scenario analysis have been conducted. Climate proofing can be included when policies are developed and implementation strategies drafted. Shrinkage literally provides space for many climate proofing measures as listed in appendix B. For example, greenhouse agriculture in urban areas, small cities, etc. Many other policy fields might be relevant based on the analysis of vulnerability and adaptive potential.

6.5. Political sweet spots and opportunities

This final section aims to highlight political sweet spots and opportunities. We consider a political sweet spot a policy area that currently receives or in the mid-term is likely to receive political attention. Closely related to political attention, are funding opportunities derived from that attention or existing funding instruments. Thus, public initiatives and funding might be(come) available that provide opportunities for coupling to implement climate proofing policies. The Netherlands Environmental Assessment Agency has already mentioned the following current or future sweet spots:

- chaotic urban structures and planning;
- industrial areas;
- climate mitigation;
- shrinkage.

6.6. Conclusions

- Climate adaptation policy is already addressed at national level via the national adaptation strategy. However, it mostly refers to vulnerability from water nuisance and flood risk and makes no reference to heat stress.
- Many instruments and existing policies are available to couple climate adaptation policy.
- To facilitate implementation and access funding, climate adaptation measures should seek coupling with political sweet spots. Policy areas that receive political attention and funding. E.g. for urban renewal seek win-win coupling opportunities with social objectives.
- This chapter presents a brief overview of existing policy. Most promising coupling opportunities exist at local or (development) project level. Further research is needed for these opportunities. Preferably for the benefit of demonstration projects.

7. Conclusions, Synthesis and Recommendations

7.1. Conclusions

This research provides a more detailed analysis of climate vulnerabilities and adaptation potential of urban areas in The Netherlands over a period of time. Climate vulnerability is analysed at neighbourhood level for the following climate effects: water safety, water nuisance (pluvial flooding), drought and heat stress. Most Dutch policy trajectories did not consider these effects nor looked at them in an integrated way, and mostly at lower detail levels. The adaptation potential was quantified per urban area, which is beyond the aim of the National Adaptation Strategy to couple adaptation strategies with spatial developments. These more detailed insights can support the operationalisation of an adaptation strategy. From the analysis on vulnerability and adaptation, the following conclusions were drawn.

7.1.1. General

High relevance of climate vulnerability

- Most of the Dutch urban areas are exposed to a (combination of) climate hazard(s). The graduality of exposure differs greatly for each urban area, per region, per urban typology and per climate hazard. However, in general, climate hazards are expected to increase.

7.1.2. Water safety

Exposure to flooding for residential and industrial area

- Over the past 60 years, there has been shift towards building in flood prone areas.
- Of the flood prone urban area, the residential and industrial areas cover approximately 75% of the area. These urban functions are therefore most exposed to potential flooding.

Cultural heritage minimally exposed to flooding

- The old city centres are hardly exposed to flooding.

Flooding from regional waterbodies could be substantial on a local scale

- The flooding depths of a regional flood could be substantial, even if the extent of such a flood is small. Areas that are not subject to flooding from the main rivers and sea could flood in the future.

Effects of climate change on vulnerability of urban areas to flooding

- It is expected that, due to climate change effects, there will be an increase in water depth, flooded extent and flood duration. The vulnerability of urban areas to flooding is expected to increase most in the coastal areas where these effects are foreseen to be the largest.

No regret measures for water safety can be achieved by coupling with measures which reduce pluvial flooding impacts

- Currently, the coping capacity for flooding is low, although efforts are being made to improve flood event management. Overview of possible spatial planning measures is available, but there is not enough information available on the risk reduction effects when implementing these measures. For areas where the expected water depth is lower than 1 metre, coupling with measures that reduce the impact of pluvial flooding is possible. At present, much attention is given to flood event management. It is therefore advisable to also evaluate spatial measures which support evacuation strategies.

7.1.3. Water nuisance

No strict relation between urban typologies and water nuisance

- Except for downtown areas, a strong relation between urban typologies and water nuisance is lacking;
- Because most cities are located on flat areas, small perturbations in the urban morphology (local depressions) can result in flood prone areas;
- The lack of a relation with urban typology and water nuisance may be a reason to choose to avoid national policy on this topic. Responses are to be developed according to local situation.

Differentiate between frequent and extreme events

- For frequent floods, cities based on sand layers are less susceptible to floods than cities based on clay layers;
- In case of extreme events, this relation dissipates;
- Although the effects of extreme events are moderate, in a limited amount of areas flood stages of more than 50cm can be expected;
- The effects of climate change are modest, but might require an upgrade of the current standards for frequent flooding.

Focus on downtown areas

- City centres are particularly prone to water nuisance;
- The effects of frequent and extreme events are proportional. Downtown areas are therefore suitable candidates for regional or national policies.

Groundwater nuisance may occur in every city

- There is a clear relationship between the dynamics of the groundwater and surface water systems and the features of the different geographical regions in The Netherlands. How and when groundwater nuisance occurs idepends on the geographic situation.
- Nonetheless, groundwater nuisance caused by high groundwater levels occurs throughout the country, though lower lying neighbourhoods around the city centre are more susceptible. There seems to be no particular relationship between the geographic region a city is situated in and the occurrence of groundwater nuisance. Local factors are more determining.
- Buildings older than 1990 and in particular older than 1960 are vulnerable, as well as trees in urban parks in drainage dependent areas.
- After World War II more houses were built in drainage dependent areas than in naturally discharging areas.

Though an increase of groundwater nuisance will occur, possibilities to overcome this are readily available

- About half of the buildings and more than half of the city parks in The Netherlands are situated in drainage dependent areas and need active artificial drainage. This percentage will slightly and gradually increase in the coming decades. There are enough possibilities within the context of existing plan development processes to take necessary measures during renewal.
- More than 84% of new urban areas are planned in drainage dependent areas. Adequate cost effective technologies to prevent groundwater nuisance are readily available. Plan developers should however be aware of the specific conditions that count when building in drainage dependent areas.

In general, the larger the distance is towards open water or drainage systems, the more exposed an area will be to (ground)water nuisance and the less possibilities a water system provides to control it.

7.1.4. Drought

Historical buildings (cultural heritage) are the most vulnerable parts of our urban areas for an increase in drought caused by climate change

- About one third of the historical buildings in The Netherlands is vulnerable for drought. Since climate change will cause an increase in drought, it can be expected that the number of historical buildings that are damaged will rise significantly.
- The costs of restoration of wooden pile foundations are substantial. This will create an enormous financial burden on house owners.
- Vulnerable historical neighbourhoods are situated in the clay and peat areas of the western and northern parts of The Netherlands.

Land subsidence caused by drought will increase, though it is unknown to what extend this will damage urban functions.

The vulnerability of urban parks and trees to drought is not well known

- Though depletion of the soil moisture content is expected to increase during extreme periods of drought, it is difficult to say how many trees will not survive these expected extreme droughts.
- Soil sealing of urban areas prevents rainfall from infiltrating and replenishing both the groundwater and the soil moisture content in the root zone. Therefore, soil sealing enhances the impact of drought.

In general, the less the distance is towards open water or water storage facilities, the more possibilities the water system provides to compensate the effects of drought.

7.1.5. Heat stress

Downtown areas are prone to heat stress; other areas show a large variability

- Especially in downtown areas, a clear relationship between land use/cover and heat accumulation exists.
- This relation is weak for other urban typologies. This is mainly because of the spatial differentiation between and within cities; industrial and office areas are not necessarily susceptible to disproportional heating.
- During heat waves, temperature differences increase.

- Especially in areas with intensive use of public space (e.g. shopping areas), the effects of heat stress could be substantial (usability, health, economy).

Use space wisely

- Urban vegetation and urban water have a cooling effect on ambient temperature. Vegetation seems to have a larger cooling effect than surface water;
- Densification policy may have adverse effects, because it increases the percentage of paved surface and leaves less space for cooling elements such as vegetation and water;
- Very high densities on the other hand provide shade and are therefore reducing the exposure to heat stress;
- Large contiguous green (vegetation) or blue areas (surface water) have a disproportionaly larger cooling effect.

Differentiate between indoor and outdoor temperatures

- Heat stress has a severe effect on the usability of public spaces;
- The most commonly used 'adaptation measure' against heat stress for interior space is air conditioning, which in fact causes CO_2-emissions and extra outdoor heat. The reduction of the urban heat island effect by a proactive urban planning will reduce the demand for air conditioning and therefore reduce CO_2-emissions and outdoor heat.

7.1.6. Adaptive capacity and measures

Mainstreaming adaptation with urban renewal could lead to a significant reduction of vulnerability

- At present there is a huge opportunity for linking adaptation with urban renewal: about 43% of the building stock has reached its expected end of lifespan.
- Renewal cycles give insight in time to wait before the next opportunity for implementing adaptation measures is expected to arise. This may assist in long-term thinking.
- When no action is taken, opportunities for linking adaptation to urban renewal are missed. On average, it takes 50 years before new large scale opportunities arise.
- If areas reaching the expected end of lifespan would actually be redeveloped, by 2050, 92% of Dutch urban extent could be protected against the investigated climate hazards (method not comprehensive).
- The produced outcomes are sensitive to perturbations for a range a variables.

Selection of adaptation measures

- Selection of adaptation measures requires knowledge of local design properties
- There is insufficient knowledge about effectiveness and cost-benefit ratio of measures. However, question is whether this will ever be clear, because of the complex dynamics of urban systems.
- Technical solutions for adaptation are readily available in all different urban typologies.

Maximize the no-regret zone

- No-regret measures should be implemented when the opportunity emerges, as their costs are negligible to low.
- Around 50% of all identified adaptation measures to water nuisance, drought and heat stress have a no-regret potential. For water safety, the costs for most identified measures are significantly higher so there is a greater risk for 'high-regret'.
- There are many ways available to increase coping capacity without the potential of future regret (all categories).

Maximize linking with mitigation strategies

- There is more awareness within society for climate mitigation then for climate adaptation. Therefore, mitigation could open opportunities for adaptation.
- Adaptation to heat offers many synergy opportunities with mitigation.

Stakeholder involvement

- There is a wide range of actors involved. Regional government (provinces) have limited ways of directly influencing the realization of specific adaptation measures.
- Water safety is an issue for all levels of government.
- Water nuisance and drought is predominantly an issue for regional and local government.
- Heat: is more of an issue for local government, private companies and the community.

7.1.7. Existing policy

Existing policy recognizes relevance and urgency, but lacks the step of putting it into practice

- Existing policy, especially the National Adaptation Strategy (NAS), anticipates climate vulnerability and its expected increase and embraces the potential to couple adaptation strategies with spatial developments. However, this should be more operationalised. The NAS already stresses relevant instruments at various scale levels, but recommendations on the practical incorporation of climate adaptation objectives and strategies into these instruments are still lacking.

7.1.8. Robustness of the conclusions to different scenarios

This study aims to deliver scenario-robust outcomes. This means that their validity should be assessed for all future scenarios. In Appendix E, the consequences of different socio-economic (CPB, 2004) and climate scenarios (KNMI, 2006) are described for each of the conclusions. The key findings are presented below:

Socio-economic Scenarios

- The damage sensitivity of cities is expected to be significantly higher in the internationally oriented scenarios (Strong Europe and Global Economy), compared to the nationally oriented scenarios, due to high population growth and high economic growth.
- This increased sensitivity may have significant consequences for adaptation.
- Active adaptation is possible only in the scenarios with a strong public sector (Strong Europe and Regional Communities) because the other scenarios lack effective environmental policies.
- Opportunistic adaptation is possible in all scenarios. In the scenarios with a strong focus on the private sector (Global Economy and Transatlantic Market), opportunistic adaptation is the only feasible option because effective environmental policy is lacking.
- However, in these scenarios (GE and TM) it can be expected that adaptation will only take place if the benefits for the private sector exceed the costs and if required knowledge is readily available. Thus, market incentives and guidelines play a crucial role here.

Climate Scenarios

- Have a marginal influence on the vulnerability to average climate conditions in the next century (W and W+ are slightly more hazardous).
- G+ and W+ have increased extremes of drought and precipitation in summer. This increases vulnerability to drought and water nuisance.
- Have little influence on the conclusions that resulted from the adaptation analysis.

7.2. Synthesis and policy recommendations

What actions should we take?

1. Start climate adaptation of urban areas now. Climate adaptation policy should be formulated and activated as soon as possible at all levels of government – local, regional, national and even at European level – because (1) cities are relatively vulnerable to (extreme) climate effects and will become even more so in the future without adaptation and (2) any delay in implementation means missing opportunities for timely low-cost responses:
    - In general, but depending on local conditions, current urban design enables cities to deal relatively well with average climate conditions and provides some headroom for change. (CH4)
    - However, exposure to extremes will become problematic in certain areas. (CH4)
    - Climate predictions point towards more intense and frequent extreme events in the future (CH2)
    - Densification, expansion during economic growth, aging of infrastructure and limited adaptation possibilities of cultural heritage will all lead to an increase in damage sensitivity of cities and therefore of the vulnerability, regardless of climate change. (CH2)
    - Many useful measures are readily available to mitigate the consequences of the predicted climate change and can directly be implemented (CH5). Therefore, lack of knowledge is no argument to postpone adaptation.
    - The Dutch climate and urban geography are suitable to create sustainable green corridors, city parks and open water in urban areas. When these functions are evenly distributed in the urban environment, they substantially help to mitigate the unwanted consequences of pluvial flooding, groundwater nuisance, drought and heat stress. (CH4)
    - Significant parts of our urban areas will need renewal in the next coming decades. And many measures are low-cost and low-regret if implemented during urban renewal projects (CH5).

  - Important knowledge gaps are the quantification of effectiveness of a few of the proposed measures and the stakeholder and community receptiveness to these measures.

How to approach adaptation?

2. A structural focus on how and where we can adapt easily, with no or low regret measures, will result in a substantial increase of the climate robustness of our urban areas in the coming decades:
   - Opportunistic adaptation where possible, active adaptation where necessary.
   - At present, there is a large window-of-opportunity to significantly reduce the vulnerability of cities before 2050 by using the opportunities for synergetic effects that are provided by autonomous urban renewal dynamics. (CH5)
   - If this opportunity is not being used now, it takes at least 50 years before a new opportunity arises. (CH5)
   - Many no and low-regret measures are available, that have the potential to come at low additional cost to conventional urban design, if designed smartly and if implemented during an urban renewal project. (CH5)
   - Knowledge gap: research to improve the adaptive potential is still in its infancy.
3. Tailor-made responses that are re-evaluated on a regular basis. A one-size-fits-all approach to adaptation does not exist.
   - The degree of climate vulnerability and response options depend strongly on local and situational conditions. (CH4/5)
   - Climate vulnerabilities and adaptation potential are to be considered in an integrated way. (CH4/5)
   - Continuous re-evaluation of ongoing climate adaptation is needed, because measures that are implemented now may over time result in unforeseen problems to unforeseen stakeholders because of ongoing change (CH5). This underpins the necessity to integrate flexibility into the measures and governance structure.
4. Inclusion of climate adaptation in existing policy instruments is likely to be most effective.
   - The sooner climate adaptation is implemented at all levels, the better urban society will be in avoiding potential damage. (CH4)
   - Climate adaptation is to be included in policies on spatial planning, water management, disaster reduction and public health at national, regional and local level. To be included are issues of flooding, drought and heat. (CH6)
   - Regional and local spatial plans should include information on climate vulnerability and on adaptation strategies and measures, following the proposed three-step approach. (CH6)
   - This adaptation paragraph should distinguish between various planning horizons, e.g. 10, 20, 50 and 100 years, and should take the end of lifecycles of buildings and infrastructure in consideration.
   - The adaptation paragraph should contain a brief analysis of all vulnerabilities, including graduality.

Where should we adapt our urban areas?

5. Highly sensitive areas and vulnerable objects and infrastructure such as industrial and commercial areas, dense city centres, cultural heritage, hospitals, power and telephone networks require special attention.
   - In particular extreme events have the potential to cause excessive damage in these areas and to these objects. (CH4)
   - If no action is taken, this will become worse in the future, as their value to society increases. (CH2/4)
   - Cultural heritage is especially prone to adverse effects of drought, as the possibilities for adaptation of these functions are very limited. (CH4)
   - Industrial and commercial areas are more prone to coastal, fluvial and pluvial flooding than residential areas, because of higher direct and indirect damage potential. However, residential areas may be more susceptible to societal impacts. (CH4)
   - Dense city centres are highly sensitive to all themes. The presence of cultural heritage in these areas increases the sensitivity even more. (CH4)
   - A significant reduction of the damage can be achieved by extra protective measures for vulnerable objects and infrastructure (CH4)
   - City centres have a relatively high sensitivity to all studied climate effects. (CH4)
   - Knowledge gap: at present, methods for accurate quantification of damage sensitivity are not available. Especially, knowledge about indirect damages such as costs of disruption of society is in its infancy. (CH4)
6. Highly exposed regions also require special attention.
   - Although geophysical characteristics of a location are relevant, the exposure of a particular urban area depends in the first place on its design, including factors such as the percentage of paved area, ground level profiles and drainage systems. (CH4)

- Heat stress is the only climate effect for which a strong relation between exposure and urban typology is derived. High density centres are exposed the most. (CH4)
- In general, the low-lying western part of The Netherlands which has predominantly peat and clay soils is relatively more exposed to climate effects than the higher eastern and southern part of the country. (CH4)
- Knowledge gap: it is not possible to express the magnitude of exposure in absolute terms.

Who needs to do what?

7. Climate adaptation requires mostly local action and needs to be supported on a regional and national level.
    - Problems with pluvial and/or groundwater flooding, with drought and with heat stress are mostly local in terms of exposure and damage sensitivity. They can differ between locations at short distance. However, solutions may in many cases lay partly on regional level (e.g. water supply during periods of drought). (CH4)
    - Windows-of-opportunity for climate adaptation also have a local character: Urban renewal takes place on building, building block or neighbourhood scale. (CH5)
    - Most new developments are taking place under the mandate of regional and local administrations. Urban renewal projects take place under the mandate of housing corporations, municipalities and private property owners. These are the parties to be made receptive to climate adaptation. (CH6)
    - Support opportunistic adaptation through incentives for local governments, private sector and the community. Examples to consider are subsidies, tax savings, awareness campaigns, courses, fines etc.
    - Provide guidance and support: guidelines, knowledge networks, direct assistance for design of adapted public or private property, etc.
    - Water safety for coastal and fluvial flooding has a regional character and needs to be addressed by regional and national authorities.

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A Methodology per theme

A.1. Water safety

In The Netherlands water safety is mainly evaluated on a scale of a dike ring. For this study, therefore the emphasis was put on gaining more insight into the exposure of the urban area to flooding. This was performed through a GIS exercise. The following maps were combined to gain insight into the general exposure of neighborhoods, the exposure of city functions and in relation to the age of neighborhoods:

- *Age of neighborhoods* was determined through a combination of the 'woning- en populatiebestand 2008' and the CBS 'Buurtkaart met cijfers 2008'. The age of the neighborhood was determined by the majority of buildings within the neighborhood with equal age;
- *Stedelijke milieus 2006* (Ritsema et al, 2009);
- Water depth map for current situation.

The damage calculation were performed using the HIS SSM version 2.5 (Groot Zwaaftink and Dijkman, 2007). Direct and indirect damages were calculated although the number of casualties was not considered.

A.2. Pluvial flooding

Water nuisance covers the problem of urban flooding as a result of storm water excess (pluvial flooding). Excessive rainfall exceeds the natural and storm water drainage capacity and results into the formation of puddles, flooded infrastructure and eventually the flooding of buildings. Within The Netherlands, pluvial flooding in urban areas usually doesn't result in dangerous flash floods resulting in casualties, injuries and structural collapse. The combination of morphology (cities are located in mostly flat areas) and moderate precipitation levels will even in extreme events lead to the flooding of basements and damages in household inventory on ground floor level as well as traffic interruption due to flooded tunnels and roads. Nevertheless, urban pluvial flooding should be treated seriously; over the years, the accumulation of local events has resulted in substantial aggregate damages (Ten Veldhuis, 2009). These are often underestimated since not all municipalities keep structured records of individual cases. Furthermore, since damages to individual households are minor, claims to insurance companies hardly stand out.

Since pluvial flooding is determined to a large degree by storm water drainage capacity and groundwater levels, increasing precipitation levels due to climate change will evidently increase the threat of urban flooding (both in frequency and severity). The impacts of this treat is largely determined by the spatial distribution of residential areas, working environments, main infrastructure and other urban function vulnerable to flooding. Since these differ substantially from neighborhood to neighborhood, direct and indirect consequences of urban flooding are difficult to determine with certainty. Only detailed studies in which individual building, road and other characteristics are taken into account such assessments can be made. Furthermore, when local flood levels are relatively low, it is virtually impossible to model the consequences without detailed empirical data. Therefore, the main emphasis in terms of quantification within the topic of water nuisance is on the exposure to pluvial and groundwater flooding.

Finally, it is important to note that the occurrence of pluvial floods is determined by local rainfall events. Geographical distribution of rainfall intensities as a consequence of climate change is currently performed by downscaling climate models to a higher level of detail. Recently, the Dutch Meteorological Institute (KNMI) updated their 50km resolution models to a more detailed 6km grid (Klein Tank and Lenderink, 2009). Due to the relatively small territory covering The Netherlands this updated model incorporates a high level of uncertainty. Therefore the studies for pluvial flooding have been performed with a uniform rainfall distribution, therefore focusing on the city as a receptor of rain instead of the characteristics of the rainfall event itself.
The occurrence of water nuisance in the urban extent is a complex phenomenon which is determined by precipitation, soil characteristics (including land use), morphology, storm water drainage networks and groundwater characteristics. The occurrence of urban flooding as a result of rainfall (pluvial flooding) is dictated by the same principles

as elsewhere in the hydrologic cycle. Yet, two distinct characteristics differentiate urban flooding from those occurring in rural areas:

- The predominance of impervious surfaces
- The presence of man-made storm water drainage systems.

This makes the response of an urban catchment to rainfall much faster than for rural areas. Furthermore, impervious surfaces (e.g. paved roads) prevent water from infiltrating into the soil resulting in larger runoff volumes which could eventually lead to urban flooding. Although the drainage systems of some cities depend on natural channels, Dutch cities depend on a storm water drainage network for the removal of storm water. The predominance of impervious surfaces in the urban environment is boosted by relatively high groundwater levels which especially in the western parts of The Netherlands limit the drainage capacity of pervious surface areas (e.g. parks). This makes the storm water drainage system the dominant structure for storm water management. Dutch storm water networks are typically designed to withstand a 2 year rainfall which corresponds to 20mm within 1 hour. If this value is exceeded some local flooding in the form of puddles can occur. Large scale urban flooding should occur only during a 100 year or more rainfall event. This occurred for instance in the city of Apeldoorn on July 3rd 2009 where local storm water levels accumulated to more than 70mm within a few hours.

The current state-of-the-art in modeling pluvial flooding consists of coupling 2d overland flow models with (1d) storm water drainage models and 2d/3d groundwater models. The combination of a given rainfall event exceeding the maximum capacity of infiltration into impervious areas and storm water drainage systems, results in surface runoff which flows into local depressions. The resulting puddles vary in extent and depth depending on local morphological characteristics.

Generally, the data requirements, complexity and model calibration limit the use of sophisticated models to detailed case studies on neighborhood level. Application for large scale urban analysis as performed in this study is therefore not feasible and substantial schematization of the problem is required to keep requirements manageable. Therefore a hybrid approach has been adopted in which the different factors determining the problem of water nuisance have been separated. First of all, the problem has been divided into a subsurface and surface component. The subsurface model handles potential flood problems occurring from groundwater levels while the surface component handles surface runoff as a function of precipitation, morphology and land cover.

Runoff determination

Schematization of surface runoff modelling within this study is performed under the following set of requirements:

- Value and express individual morphological differences within urban areas;
- Value and express differences in land cover patterns;
- Integrate soil characteristics (top layer);
- Calculate flood extent and stage for a given level of uniformly distributed precipitation;
- Calculate results within feasible computational resources and time.

To achieve this, a combination of a standard Runoff and a Flow Accumulation calculation has been developed for a relatively high level of detail. The Runoff determination is performed by the classic Curve Number assignment method and fulfills the requirements for soil and land cover characteristics. The Flow Accumulation calculation on the other hand integrates the morphological differentiation which gives rise to flooding of micro-watersheds within cities.

In theory, the absence of a stream network or overland flow model potentially could result in large error margins. In case of overtopping of micro-watersheds, the water is not transported into adjacent basins and downstream flow accumulation is not accounted for. Yet, the majority of cities within The Netherlands are located in relatively flat areas without large differences in elevation on city level. Flashfloods as a result of channeling and substantial differences in elevations are therefore unlikely to occur. Furthermore, the expected precipitation levels and corresponding flood stages are relatively low resulting in only very local waterlogging or flooding.

The only factor that might compromise results is the absence of a storm water drainage network which is found throughout every Dutch city. These are omitted because of data requirements as well as computational load (inclusion would require more sophisticated models with much larger runtimes). As a rule of thumb, the network provides a baseline level: precipitation levels beyond the 2 year event result in local flooding because of storm water drainage saturation. This assumption is only usable as a heuristic since the network is not saturated linearly for all locations; downstream parts of the network are saturated earlier than upstream parts. For extreme events though (e.g. a 100 year return period or more) the influence of storm water drainage is minimal. Cities would simply behave like imperviously covered areas without any storm water drainage network.

1. Using the land-use and soil characteristics

- Method: Using the Curve Number (CN) method;
- For the urban extent (various rates of imperviousness);
- Identify land-use and re-map the classes to standardized land-use classes;
- Identify the soil group;
- Determine the aggregate runoff for every feature using the CNs.

Simple runoff calculation can be performed by using Curve Numbers based on the methods developed by the Soil Conservation Service (SCS, 1957, 1964). This method has been applied in a large number of case studies to characterize runoff behavior in both urban and rural areas. The method addresses both land cover as well as soil conditions which are represented as hydrological soil groups with corresponding infiltration capacities. Note that the method does not account for any flooding; it is mainly used as an indicator for areas which are likely to be flooded. The method simply calculates the ratio between infiltration and runoff for a given precipitation event (e.g. Bedeint and Huber, 2002). High runoff levels indicate a likelihood for flooding.

The acknowledgment of infiltration in the method results in non-linear runoff rates; e.g. lower precipitation levels will be infiltrate substantially into sandy soils, while for higher levels saturation leads to disproportional runoff generation.

As an operational model, the algorithm developed by Zhan et al (2004) has been used on a 1:10000 dataset for land use in combination with the Dutch national soil map using a 1:50000 scale (FRG&plus). Since the land use classes differ from the land cover classes in the model, some mapping has to be performed which can be error prone (Dutch land use classes do not necessarily coincide with American land cover classes). Fortunately, both the dataset as well as the runoff model provide a wide range of land use and land cover classes that seem to fit quite optimally. Since the model only uses the standard 4 hydrological soil groups, the level of detail within the soil map is sufficient for mapping.

2. Using surface morphology Method: Calculate Flow accumulation

For all impervious surfaces in the urban extent:

- Identify local depressions (sinks) using a 25x25m Digitial Elevation Model (DEM):, resulting in a subdivision of the terrain in micro-watersheds;
- Define the capacity of every micro-watershed;
- Fill the watershed by applying a uniformly distributed rainfall event (e.g. a 40mm rainfall event). Distribute the water within every micro-watershed;
- Assess the water stage at every micro-watershed, resulting in flood depths and extent per micro-watershed.

The method using flow accumulation is relatively straightforward. Note that this method is only applied to impervious surfaces (except buildings) since soil conditions in pervious areas influence the drainage capacity; the model is used to determine flooding on streets and other hard surfaces. Furthermore, since no overland flow is calculated, the flooding of pervious areas wouldn't influence flood stages at adjacent impervious areas. Besides, flooding of pervious areas (e.g. green zones) wouldn't add up to the overall flood vulnerability since no primary functions (living, working, commuting) are located.

The process consists of basically two steps. First the micro-watersheds are determined using the DTM, resulting in sets of adjacent basins. The guiding principle for this determination is the existence of local depressions in the morphology, where cells are assigned around the lowest local level of depression in their vicinity. Since only an elementary stream model is applied, no smoothing of the DTM is required to overcome the problem of single cell sized sinks. Thus, micro-watersheds consisting of only 1 cell (25 x 25m) exist which is vital to identify local floods (or even puddles).

Secondly the basins are filled by a chosen precipitation level resulting in different water stages both between and within the basins. A simple algorithm is used to determine the distribution of precipitation over the different cells within the basin, making sure that the deepest cells (sinks) are filled up first. This means that inter-basin flow is not accounted for, which in theory means that basins could give rise to flood levels beyond ridge levels. For the precipitation levels used in the model runs tough, this never occurred.

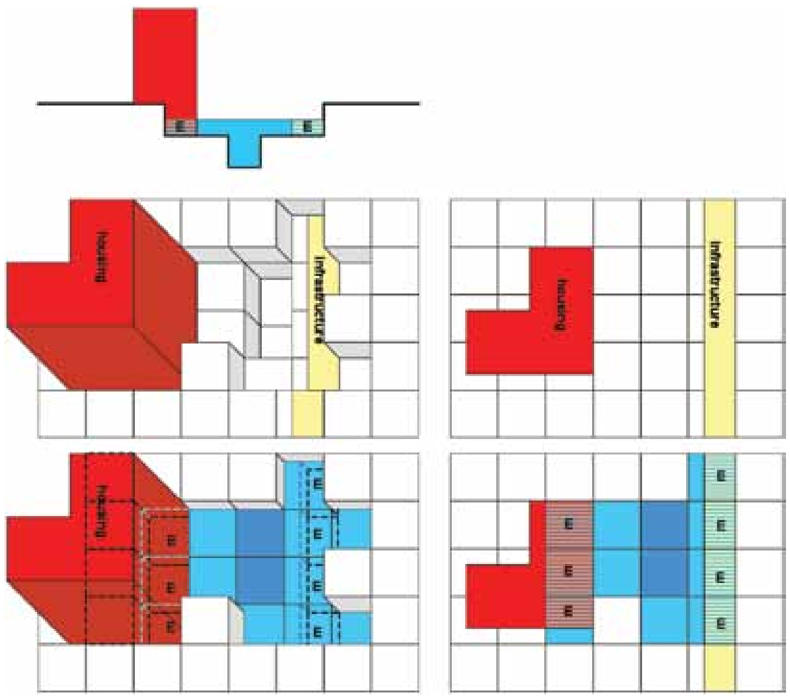


Figure A.1 Schematic overview of the flow accumulation method, where the exposed areas are indicated by 'E'

Note that the method does not accommodate any expression of time. Precipitation events are based on aggregate values for a chosen period. Yet, the effect of peak flows in the model would not be noticeable since no overland flow model is applied. For the model runs, daily precipitation levels are used. These provide the expressiveness in temporal sense (pluvial urban flooding of impervious areas often occurs within a day or less) combined with adequate precipitation aggregates to result in noticeable effects (the spatial resolution wouldn't accommodate local floods using hourly precipitation levels).

Finally, flooded micro basins in the proximity of surface water are discarded. Because of overland flow into channels and lakes, flooding as a result water accumulation on land areas is not likely to occur in reality. Flooding of the areas as a result of overtopping of channels on the other hand is covered in the Fluvial flooding work package.

Data considerations

The 25m resolution DTM (Actual Hoogtebestand Nederland) is currently the dataset with the highest level of detail covering all of The Netherlands. The forthcoming 1m resolution DTM might result in better outcomes, but requires computational resources for modeling beyond what's available in the project team. Also LIDAR data which generally is available at a higher resolution is not available for the urban extent covering all of The Netherlands. Furthermore, using a higher level of detail increases computational loads to levels well over those feasible for within the project. Note that a 25m resolution might omit smaller streets in densely populated areas (e.g. historical cities). The land use dataset which is used to determine the land cover is based on a 1:10000 scale (Top10 Vector). While this dataset is precise enough to differentiate between individual streets (including different classes of streets) and buildings, the elevation levels might not always correspond. Potential flooding locations in dense areas might therefore be ignored. To overcome this problem, the CN-based method is applied which indicates flood vulnerability regardless of elevation.

Model calibration

The CN-based model has been extensively used and doesn't, in the implementation used in this project, provide much room for calibration. Nevertheless, an argument can be made against the soil group classification since one of the underlying assumptions in the model is the available infiltration capacity per hydrological soil group. In a worst-case scenario, due to extensive periods of rainfall before the measured event, the soil is completely saturated. In this case the calculated runoff for especially sandy soils is underestimated (Sen and Altunkaynak, 2005). Since the model does not provide actual flood stages, calibration using actual flood records is difficult if not impossible. On the other hand, the model using morphological properties to determine pluvial flooding on impervious surfaces, is open for extensive calibration. Within the project two sources have been used:

- Expert knowledge (model verification);
- Case study data (model validation).

In important addition to the model based on expert knowledge is the implementation of a proximity function to surface water. Since surface water (lakes, channels) act as retention areas for pluvial flooding (overland flow), flooded areas in the proximity of surface water are discarded from the results. Furthermore, after extensive discussion with experts, the decision was made not to add any schematization of the urban storm water drainage network since characteristics differ substantially between urban areas.

For model validation, two case-studies have been used: Delft and Rotterdam. The department of civil works in Delft provided us with actual flood records from recent years. These gave insights into the geographic distribution of pluvial flooding to which the model could be fitted. Adjustment of some of the internal parameters resulted in a fit for which all the reported floods can be perceived in the model outcomes. Yet, the model generally overestimates the occurrence of urban floods due to the absence of a storm water drainage model. To compensate for this phenomenon, modeling results from the Pluvial Flooding workgroup for the Hotspot study Rotterdam have been used. Within this project, pluvial flooding has been determined coupling a 1D-storm water model with a 2D overland flow model. One of the most important observations was that the model used within the KNBL-study performed relatively accurate for low frequency events (e.g. a 100 year precipitation event). While this result seems straightforward since the influence of storm water drainage for such an event is minimal, the differences between the two models were in the margin of 10%. Assuming that the simplicity of the developed model for the KNBL-study could potentially result in a large error margin, this proves the model’s value.

Groundwater nuisance

The vulnerability of an area to structural groundwater nuisance can be assessed by looking at the drainage depth. This is the depth of the phreatic groundwater level underneath the surface level. Phreatic groundwater levels can vary substantially in space and time. Within urban areas groundwater levels are strongly influenced by local circumstances (eg. presents of drainage systems, leaking sewage systems, soil sealing, presents of parks and gardens, etc.) For every neighborhood in urban areas the groundwater levels and subsequently the drainage depth is determined by the National Hydrologic Instrument (NHI). This instrument only provides a rough indication at this stage and the results should be considered as an indication.

Conclusion

The methodology to assess water nuisance focuses on the exposure to pluvial flooding and groundwater levels.

A.3. Drought

There are no quantifiable spatial indicators available to determine the vulnerability of specific urban functions. The vulnerability of buildings has therefore been determined based on several indirect indicators such as the appearance of clay and peat layers in the subsurface and the age of buildings. Existing geo information has been used to determine the amount of historical buildings that are vulnerable for drought. In Chapter 4 the vulnerability criteria are explained in more detail.

A.4. Heat stress

The problem of heat stress covers a differentiation in temperature distribution as a result of land use and land cover. Generally, cities absorb more solar radiation than rural areas since the thermal capacity of materials (e.g. concrete, asphalt) is larger. The cooling effect of evaporation, which withdraws heat from the environment, is relatively low due to the limited amount of vegetation and surface water. Furthermore, building areas provide barriers that prevent wind to cross a city; the accumulated heat is therefore not transported elsewhere and remains within the urban environment. Finally, extensive heat accumulation in the built environment is released only gradually during evenings and nights resulting in a temperature gap between city and countryside. During long heat waves, the process of heat accumulation is heightened since not all absorbed heat is released during nighttime. Therefore surface areas (e.g. parking lots) are already ‘warmed up’ in the mornings, accumulating even more heat during the coming day.

In general cities show considerably higher temperature levels (surface and air) than observed in rural areas which is know as the urban heat island (UHI) effect. Heat stress causes health effects (increased level of mortality rates and hospitalization) as well as a reduction in productivity and general comfort in both public space and buildings. The 2003 heat wave covering major parts of Europe resulted in an estimated 70.000 heat related fatalities (Robine et al, 2008).

Modeling the effects of a given heat wave on health, productivity and other domains is extremely complex since it involves extensive knowledge and data on demographic and behavioral aspects (e.g. individual responses, working culture) as well as a deep insight in the physical characteristics of the built environment. Estimations are mainly based on empirical data from past occurrences. Within The Netherlands, research on the effects of heat waves on cities and on the UHI effect as a whole is very limited. It is therefore not feasible to develop a model that performs quantitative estimates of expected effects, let alone to make solid future estimates as a result of climate change. Within this study, the emphasis of vulnerability assessment for the topic of heat stress focuses on the exposure; i.e. the geographical distribution of temperature deviations compared to a given mean temperature.

Currently, models for estimating air temperatures for a given urban setting are data intensive, complex and unfit to be applied to a large number of cities. Nevertheless, for this project was required that incorporates (a subset of) the relations between urban characteristics and the UHI effect.
Since surface temperature data provided through remote sensing is widely available and thus usable for calibration, the model focuses on developing the relation between urban land cover and surface temperature. This resulted in the following set of requirements:

- Focus on surface temperatures in public space;
- Ability to relate land cover to temperature deviations;
- Ability to incorporate the effects of shade;
- Incorporation of heat accumulation for rising temperatures above and below average temperatures;
- Confirmation of heating and cooling effects of features beyond their physical boundaries (buffering);
- Computationally inexpensive enough to cover all the urbanized areas.

This has been achieved by combining a land-cover temperature function, a shading model and a buffering model into a model that holds somewhere between a surface temperatures and an air temperature model. The actual parameter values to express relations correctly have been determined through a relatively simple regression model using a training and test set.

Note that this method does not consider the influence of scaling effects. Both temperature gradients on country level as well as the accumulating effect of city size on temperature build up is not taken into account. Furthermore, the effects of air circulation (wind, urban draft) are not accommodated within the model. This might lead to overestimation of heat stress for cities located in the vicinity of rivers or sea.

1. Land cover – temperature deviation Method: assign heating/cooling function to land cover classes

- Define different heat accumulation and cooling levels per land-cover class including different building- and road types based on a 1:10000 land use map;
- Apply a shading model using a 25m DTM for summer solstice (longest day) and incorporate temperature adjustments resulting from the shading model;
- Calculate buffers around features depending on temperature, size and class (e.g. forests, surface water) and calculate temperature gradients within overlapping buffers;
- Measure resulting average temperature for land cover classes (excluding housing) for a given temperature.

The initial definition of the heating and cooling levels for land cover classes is based on the results of literature studies and expert interviews. Typically, paved surface areas (e.g. parking lots, roads, rooftops) are initialized at levels ranging from 2 to 10 degrees. Green and blue urban zones (parks, surface water, grassland, etc.) on the other hand are initialized at levels ranging from 0 to -10 degrees. The resulting mapping function is applied to the urban areas in the Dutch National base map (vector, 1: 10000). The application of the shading model is based on the Dutch National DTM (25 x 25m) for the solstice over a complete daylight period. The gradients within resulting shading model are assigned with a cooling temperature ranging from 0 to -10 degrees. The shading is superimposed on top of the land cover – temperature model and the resulting temperature deviations calculated. Finally, a series of buffers are generated depending on a combination of heating or cooling effect and the surface area of the feature. The aim of this

model is to accommodate heating and cooling effects over distance. According to experts (NOTE INTERVIEW SPANJAARD), large heating or cooling bodies (e.g. parking lots, urban forests) can emit a heating/cooling effect up to 40 meters beyond their physical boundary.
In the model this is implemented by generating a gradient within the buffer zones, resulting in a large heating/cooling effect at close range and a liner degradation of the effect towards the buffer extent (set at 40m maximum). The buffer extent is a function of the heating/cooling body's surface area. The use of buffers implies that there are overlapping regions (either between buffers or between buffers and land cover surfaces). The temperature values of these intersections are calculated by using the sum of the individual temperature deviations.

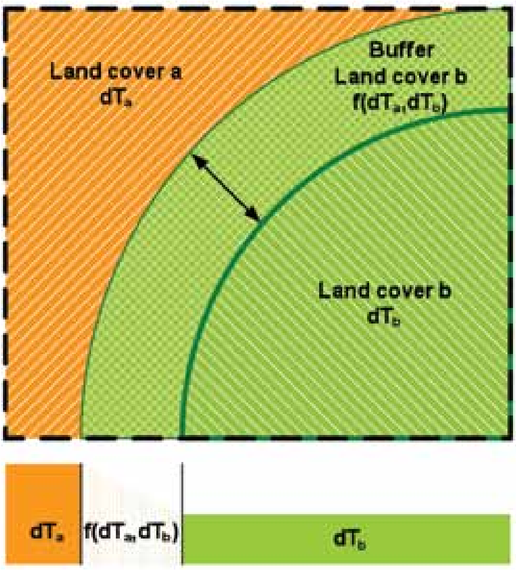


Figure A.2 Schematic overview of the models generation of a heat gradient within a buffer region between 2 land cover classes with different temperatures.

Finally, after application of the model on the Dutch national base map and DTM, the heating and cooling variables are optimized using a training set. This set consists of average surface temperatures retrieved from 15 Landsat thermal infrared images (S. Zwart, 2009; Klok et al., 2010). These satellite images were acquired in the Knowledge for Climate project Heat stress in the city of Rotterdam (HSRR05). Using a pixel-to-pixel comparison (e.g. Naesset, 1995), the overall error scores are determined after which the model is manually adjusted. Note that this process could be optimized by application of some optimization algorithm (e.g. a neural network). Actual implementation of such a model within the framework though proved to be unfeasible within the given amount of time. Nevertheless, manual adjustment proved to reduce error margins substantially to about 15% of the covered area which is sufficient for the given task.

Data considerations

The 25m resolution DTM used for the shading model is insufficiently detailed to identify small streets in dense urban areas. This has a substantial effect on the predictions since shading in these areas provides a considerable cooling effect. The results for urban typologies within center are therefore probably overestimated.

Computational considerations

The application and intersection of buffers is computationally very expensive. Although this method has been performed for the case study areas of Rotterdam and Delft, application on a similar level of detail for all of the urban zones proved to be unfeasible. For the overall results, in which temperature deviations are calculated as averages for larger areas, this might not lead to substantial errors.

Conclusion

The methodology to quantify heat stress focuses on the exposure to surface temperature deviations from a given mean temperature as function of land cover.

A.5. Graduality and convexity

When looking at a systems response towards the influence of a stressor, it is important to investigate if the responses are proportional to the input. Since it might be undesirable in risk management when consequences increase to a very high level after only a minor shift in the stressor level (e.g. a sudden increase in flood damages after only a minor increase in flood stage) a metrics is needed to measure the degree of proportionality. De Bruijn (2005) developed the concept of 'graduality' (Bruin, 2005) which measures the degree of proportionality between flood damages and river discharges. For this study the operational formula to describe graduality has been adapted to be applicable in general conditions in which some stressor level (e.g. temperature, rain intensity) relates to a system's response (e.g. temperature deviation, runoff level). Graduality G is conceptualized as follows:

$$G = 1 - \sum_{n=1} n = \frac{|\Delta S'_n - \Delta R'_n|}{2} \quad \text{(1), with}$$

$$\Delta S'_n = S'_n - S'_{n-1} = \left[\frac{S_n - S_{min}}{S_{max} - S_{min}}\right] - \left[\frac{S_{n-1} - S_{min}}{S_{max} - S_{min}}\right] \quad (2)$$

$$\Delta R'_n = R'_n - R'_{n-1} = \left[\frac{R_n - R_{min}}{R_{max} - R_{min}}\right] - \left[\frac{R_{n-1} - R_{min}}{R_{max} - R_{min}}\right] \quad (3)$$

S_n = Stressor level (e.g. in case of rainfall intensity: 33mm, 54mm, etc.)
R_n = Response level (e.g. in case of runoff: 0.01 m3/m2, etc.)
n = Ranking number of the stressor level

This results in a scalar with the range [0,1] where 0 represents a single step-wise curve and 1 represents perfectly linear function.

Graduality can act as a resilience indicator; sudden increases in climate effects create high risk levels in combination with increased uncertainty in the probability distribution. When climate is treated as a stable system, it is perfectly sensible to base a dyke system on some probability (e.g. a 10000 year flood event) since the residual risk is close to zero. Note that the consequence of a breach can are severe, so the graduality of the system's response is close to 0 since a single event beyond a 10000 year return period can cause possibly have catastrophic consequences. With increasing uncertainty in probability distributions residual risk is increasing (although nobody knows to what level). It might therefore be sensible to focus less on probability based risk management, but to put more emphasis on the response behavior (e.g. the expected loss of lives or damages). The concept of graduality is important in this paradigm shift.

The graduality values are in itself only indicators of the proportionality of the effects as a function of the input values (i.e. the rainfall intensities). They become more expressive in combination with an interpretation of the shape of the exposure progression function. The shape of a response curve can be convex or concave. In case of convex curves the initial response level of a system to increasing stressor levels is low (e.g. an increasing precipitation intensity result in only a marginal increase of damage).
For concave response curves the opposite is true: a marginal increase in stressor level results in a large response level (see Figure 3.5).

In reality, the left tail of a concave response curve is non-existent. Since no major disasters have occurred during only marginally increasing stressor levels (e.g. a relatively intense rain, or a moderate heat wave) such model outputs should be neglected. To a large extent this is caused by an incomplete model: in this study only exposure is modeled while a much more sophisticated impact model (e.g. direct damages) is absent.

Conclusion
The assessment of graduality and convexity provides a means to indicate how the exposure changes as a function of climate change without the constrains provided by uncertain exceedance probabilies.

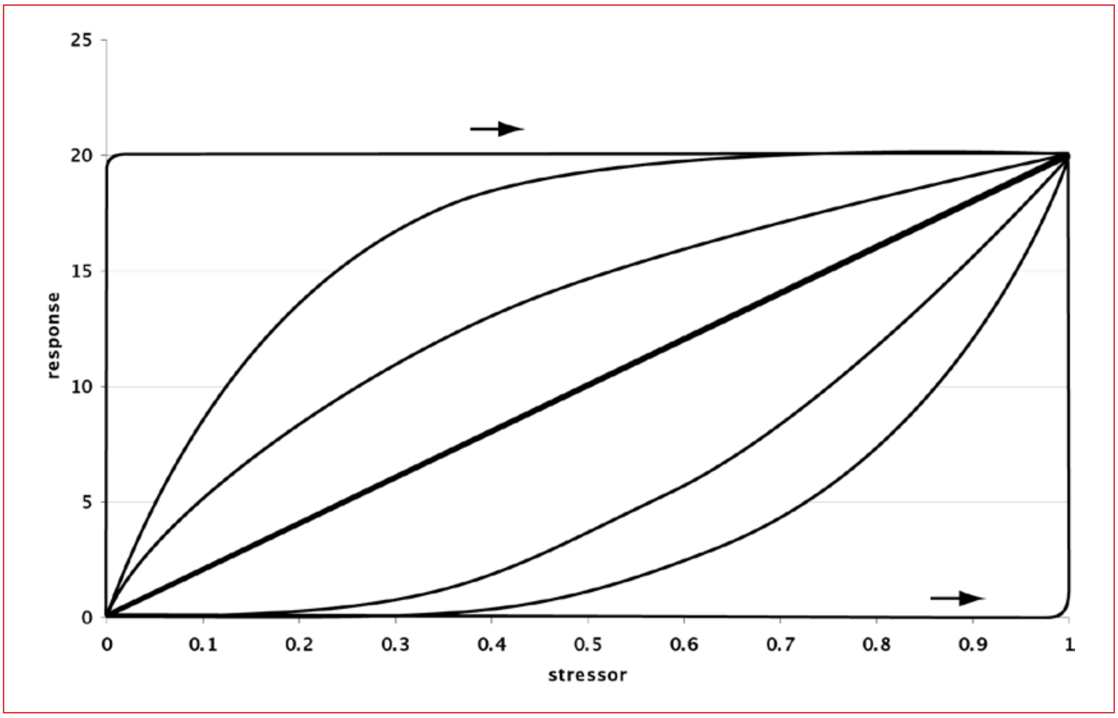


Figure A.3 Illustration of graduality and convexity given stressor and response levels.

A.6. Adaptive capacity

Within this study, the adaptive capacity is mainly determined by the expected end of lifespan of individual features (buildings, roads, etc.). For a lifespan-centered approach two main sets of data need to be calculated: Expected end-of-lifespan for the current building stock Expected end-of-lifespan for the future building stock as a result of replacement. To acquire these datasets, first of all the construction year of individual features (buildings, roads, etc.) needs to be determined. Construction periods for individual houses with a nationwide cover are collected in the Housing and Population dataset (Evers et al, 2005; Brand, 1994). A dataset covering businesses and other facilities was unfortunately unavailable within the project.

To determine the construction age for buildings other than houses, as well as for infrastructure and other features, a simple methodology was developed in which the construction age is determined by the nearest feature for which the construction age is known. The underlying assumption that surrounding features (e.g. roads) can be dated to the same period as the closest housing feature is prone to error, but seems to be the most feasible method for age assignment. Apart from the construction period, the average lifespan needs to be determined. For houses this depends on the following aspects:

- Monument status;
- Ownership (rent / private);
- Maintenance period.

Note that the maintenance period is taken into account since major upgrading cycle for existing buildings provide opportunities for climate adaptation.

Additionally, the assumption was made that the lifespan of other buildings as well as infrastructure and public space is determined primarily by function.

Subsequently, the resulting feature classes are assigned with predefined lifespan values based on expert knowledge and literature review. It is important to note that there is no actual agreement on lifespan duration. Additionally, a difference should be made between the economic lifespan which covers the period in which an object is depreciated to zero and the technical lifespan. Typically, the technical life exceeds the economic lifespan. Within The Netherlands, a large portion of the housing stock is still maintained while economic value depreciated towards zero (note that this does not express the market value which still can be substantial). Within this project the technical lifespan is taken as a starting point. An exception has been made for social housing, which is typically owned by a semi-private housing corporation. The 25 year period of iterative upgrading is standardized for social housing.

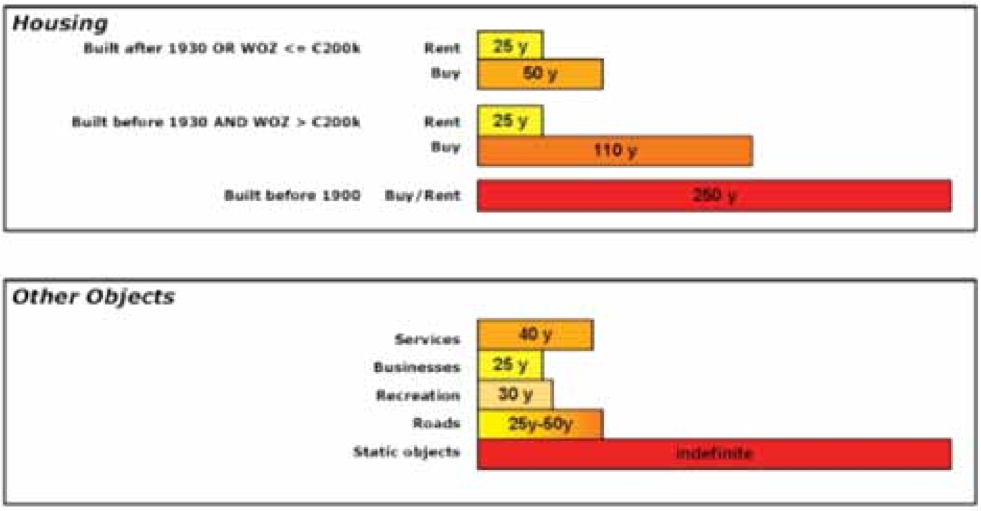
For private housing on the other hand these periods might differ from owner to owner and have therefore not been used to determine (i.e. often shorten) the earliest moment for application of adaptive measures.
In short the method comprises of:

1. Construction period – lifespan assignment. Method: assign lifespan period based on building attributes:

- Assign construction period to individual buildings;
- Assign construction periods for 'unknown' buildings and other features based on the closest known neighbor;
- Determine lifespan periods for different building types based on functional properties, ownership and construction period (e.g. monuments);
- Calculate resulting lifespan periods.

Data considerations

As for the other topics, the land use dataset used to determine the land cover is based on a 1:10000 scale (Top10 Vector). The construction age is determined by superposition of the point dataset and calculating Thiessen polygons for the actual assignment of construction ages to individual vector features. Note that for multiple points within features, the average age is assigned.



B Measures

B.1. Adaptation measures to increase the threshold capacity of urban systems

			Threshold capacity (to prevent impacts)			
			Flooding	Water nuisance	Drought	Heat
Buildings	**Construction measures**	Floating buildings	+	+		
		Amphibian buildings	+	+		
		Buildings on stilts	+	+		
		Removing living functions from ground floor				
		Wet-proofing				
		Dry-proofing				
		Building without crawling space		+		
		Elevated indoor floor level	+	+		
		Buildings integrated in flood defense	+			
		Low impact development		+	+	+
		Green roofs		+		+
		Wet roofs		+	+	+
		Building orientation				+
		Shading				+
		Reflective building materials				+
		Thermal isolation				+
	Utility measures	Irrigation				
		Aquifer thermal energy storage				+
		Protection of hazardous materials				
		Protection life support services				
		Natural ventilation				
		Breathing windows				
	Outdoor measures	Subsoil infiltration		+	+	
		More black earth in garden		+	+	+
		Moisturizing roof				
		Rain tank		+		

			Threshold capacity (to prevent impacts)			
			Flooding	Water nuisance	Drought	Heat
Infrastructure	**Embankments**	Embankments	+			
		Dams	+			
		Natural flood defense	+			
		Unbreachable embankments	+			
		Overtopable embankments	+			
		Multifunctional flood defense	+			
		Quay	+			
		Backwater flap/gate	+			
		Stop logs	+			
		Sheet piles with water pressure relieve	+	+		
		Sand bags				
		Temporary flood barriers				
		Compartimentation	+			
		Physical emergency measures				
	Ground level measures	Profiling of ground surface	+	+	+	
		Escape routes				
		Elevated main roads				
	Drainage measures	Groundwater drainage		+		
		Smart-drain		+		
		Super-drain		+		
		Separated sewer system		+	+	
		Combined sewer system		+		
		Improved separated sewer systems		+		
		Subsurface water storage facilities		+		
		Ditches and gullies		+		
	Infiltration and retention	Shallow subsurface infiltration		+	+	
		Deep infiltration		+/-	+	
		Permeable pavement		+/-	+	
		Infiltration-Transport drain		+	+	
		Moisturizing paved surfaces				
	Water system measures	Water inlet/outlet		+	+	
		Water level management		+	+	
	Waterway measures	Upstream measures	+			
		Dredging of (summer) river bed	+			
		High water ditch/canal	+			
		New rivers or canals	+			

			Threshold capacity (to prevent impacts)			
			Flooding	Water nuisance	Drought	Heat
Infrastructure	**Utility measures**	Surface water cooling				+
		More cooling water for electricity production				
		Aquifer thermal energy storage				
		Climate robust communication network	+	+	+	+
		Climate robust infrastructure and utilities				
Public open space	**Ground level measures**	Emergency retention areas				
		Emergency retention in road shoulders				
		Public space designed as flow paths				
		Water squares				
		Shelters	+			
		Stairways	+	+		
		Natural and man-made elevated areas	+			
		Landfill (NL: aanplempen)	+	+		
		Artificial islands	+	+		
		Ground level elevation				
		Profiling of ground surface	+			
		Mound (NL: terp)	+			
		Floodplain enlargement	+			
		Floodplain excavation	+	+	+	
		Natural water storage	+	+	+	
		Artificial water storage		+		+
	Green	More green (concentrated)		+		+
		More green (dispersed)	+			
	Other	Floating platforms		+		
		Retention areas				
	Total amount		33	36	15	13

B.2. Adaptation measures to increase the coping capacity of urban systems

			Coping capacity (to keep impacts limited)			
			Flooding	**Water nuisance**	**Drought**	**Heat**
Buildings	**Construction measures**	Floating buildings	+	+	+	
		Amphibian buildings	+	+	+	
		Buildings on stilts	+	+		
		Removing living functions from ground floor	+	+		
		Wet-proofing	+	+		
		Dry-proofing	+	+		
		Building without crawling space				
		Elevated indoor floor level				
		Buildings integrated in flood defense	+			
		Low impact development				
		Green roofs				+
		Wet roofs				+
		Building orientation				
		Shading				
		Reflective building materials				
		Thermal isolation				
	Utility measures	Irrigation		+	+	+
		Aquifer thermal energy storage				+
		Protection of hazardous materials	+	+	+	+
		Protection life support services	+	+	+	+
		Natural ventilation				+
		Breathing windows				+
	Outdoor measures	Subsoil infiltration				
		More black earth in garden				
		Moisturizing roof			+/-	+
		Rain tank			+	

			Coping capacity (to keep impacts limited)			
			Flooding	Water nuisance	Drought	Heat
Infrastructure	**Embankments**	Embankments				
		Dams				
		Natural flood defense				
		Unbreachable embankments	+			
		Overtopable embankments	+			
		Multifunctional flood defense	+			
		Quay				
		Backwater flap/gate				
		Stop logs				
		Sheet piles with water pressure relieve				
		Sand bags		+		
		Temporary flood barriers				
		Compartimentation				
		Physical emergency measures				
	Ground level measures	Profiling of ground surface			+	
		Escape routes	+	+		
		Elevated main roads	+	+		
	Drainage measures	Groundwater drainage				
		Smart-drain				
		Super-drain				
		Separated sewer system			+	
		Combined sewer system				
		Improved separated sewer systems			+	
		Subsurface water storage facilities			+	
		Ditches and gullies				
	Infiltration and retention	Shallow subsurface infiltration				
		Deep infiltration				
		Permeable pavement				
		Infiltration-Transport drain			+	+
		Moisturizing paved surfaces			-	+
	Water system measures	Water inlet/outlet			+	+
		Water level management			+	+

			Coping capacity (to keep impacts limited)			
			Flooding	**Water nuisance**	**Drought**	**Heat**
Infrastructure	**Waterway measures**	Upstream measures				
		Dredging of (summer) river bed				
		High water ditch				
		New rivers or canals				
	Utility measures	Surface water cooling				+
		More cooling water for electricity production				
		Aquifer thermal energy storage				+
		Climate robust communication network	+	+	+	
		Climate robust infrastructure and utilities	+	+	+	
Public open space	**Ground level measures**	Emergency retention areas	+			
		Emergency retention in road shoulders	+	+		
		Public space designed as flow paths	+	+		
		Water squares		+		
		Shelters	+	+		
		Stairways				
		Natural and man-made elevated areas				
		Landfill (NL: aanplempen)				
		Artificial islands				
		Ground level elevation				
		Profiling of ground surface	+	+		
		Mound (NL: terp)				
		Floodplain enlargement				
		Floodplain excavation				
		Natural water storage				
		Artificial water storage				
	Green	More green (concentrated)		+	+/-	+
		More green (dispersed)		+	+/-	+
	Other	Floating platforms	+	+		
		Retention areas				
	Total amount		21	21	17	17

B.3. Potential magnitude of regret of adaptation measures

In this study, three degrees of regret-potential of adaptation measures are being distinguished:

- No-regret potential: a measure has a no-regret potential when it has no adverse effects for any climate vulnerability and when the minimum increased cost potential compared to conventional development is 0.
- Low-regret potential: a measure has a low-regret potential when it has no adverse effects for any climate vulnerability and when the minimum increased cost potential compared to conventional development is low.
- High regret potential: a measure has a low-regret potential when it has adverse effects for any climate vulnerability or when the minimum increased cost potential compared to conventional development is high.

			No-Regret potential	Low-regret potential	High-regret potential
Buildings	**Construction measures**	Floating buildings			x
		Amphibian buildings			x
		Buildings on stilts			x
		Removing living functions from ground floor		x	
		Wet-proofing		x	
		Dry-proofing		x	
		Building without crawling space	x		
		Elevated indoor floor level	x		
		Buildings integrated in flood defense		x	
		Low impact development	x		
		Green roofs		x	
		Wet roofs			x
		Building orientation	x		
		Shading	x		
		Reflective building materials	x		
		Thermal isolation	x		
	Utility measures	Irrigation		x	
		Aquifer thermal energy storage	x		
		Protection of hazardous materials	x		
		Protection life support services	x		
		Natural ventilation	x		
		Breathing windows			x
	Outdoor measures	Subsoil infiltration		x	
		More black earth in garden	x		
		Moisturizing roof			x
		Rain tank		x	

			No-Regret potential	Low-regret potential	High-regret potential
Infrastructure	**Embankments**	Embankments			x
		Dams			x
		Natural flood defense	x		
		Unbreachable embankments			x
		Overtopable embankments			x
		Multifunctional flood defense	x		
		Quay			x
		Backwater flap/gate			x
		Stop logs			x
		Sheet piles with water pressure relieve			x
		Sand bags	x		
		Temporary flood barriers		x	
		Compartimentation		x	
		Physical emergency measures		x	
	Ground level measures	Profiling of ground surface	x		
		Escape routes	x		
		Elevated main roads		x	
	Drainage measures	Groundwater drainage	x		
		Smart-drain		x	
		Super-drain		x	
		Separated sewer system	x		
		Combined sewer system	x		
		Improved separated sewer systems		x	
		Subsurface water storage facilities			x
		Ditches and gullies	x		
	Infiltration and retention	Shallow subsurface infiltration	x		
		Deep infiltration			x
		Permeable pavement	x		
		Infiltration-Transport drain		x	
		Moisturizing paved surfaces			x
	Water system measures	Water inlet/outlet	x		
		Water level management	x		
	Waterway measures	Upstream measures	x		
		Dredging of (summer) river bed			x
		High water ditch			x
		New rivers or canals			x

			No-Regret potential	Low-regret potential	High-regret potential
Infrastructure	**Utility measures**	Surface water cooling			x
		More cooling water for electricity production		x	
		Aquifer thermal energy storage	x		
		Climate robust communication network	x		
		Climate robust infrastructure and utilities	x		
Public open space	**Ground level measures**	Emergency retention areas			x
		Emergency retention in road shoulders	x		
		Public space designed as flow paths	x		
		Water squares		x	
		Shelters	x		
		Stairways	x		
		Natural and man-made elevated areas	x		
		Landfill (NL: aanplempen)		x	
		Artificial islands			x
		Ground level elevation		x	
		Profiling of ground surface	x		
		Mound (NL: terp)			x
		Floodplain enlargement			x
		Floodplain excavation			x
		Natural water storage	x		
		Artificial water storage			x
	Green	More green (concentrated)		x	
		More green (dispersed)	x		
	Other	Floating platforms			x
		Retention areas			x
	Total amount		37	21	29

B.4. Potential adaptation measures for water safety

The results in chapter 4.2 give a preliminary impression of the urban intrinsic vulnerability to flooding and the vulnerability to climate change. The national water plan dictates attention for the three layer approach. This can be accomplished by improving the preparedness through event management and by spatial planning measures. Currently no spatial planning measures are implemented to reduce vulnerability to flooding and one is still in debate if this is needed. Measures taken in the spatial planning area, mostly aim at increasing the coping capacity. In The Netherlands the threshold capacity already is very high. From a cost optimization point of view it is often concluded that it is more cost-effective to invest in measures which increase the threshold capacity (heighten and strengthening of flood defences). On the other hand, great advances could be made by improving the coping capacity which in turn will reduce the vulnerability. The areas not protected by flood defenses, are dependant on measures aiming at increasing the coping capacity as the threshold capacity in these areas can not be improved.

Spatial planning measures can be divided into the following main groups:

Reducing exposure:

- *Embankement*: the overtoppable dike reduces the water depth.
- *Compartimentalisation*: can be applied to provide additional protection to vulnerable areas.

Reducing sensitivity through zoning and building regulations:

- *Zoning*: restrict from building in casualty prone areas. This measure is applicable to new developments. Although one could choose not to rebuilt an end of life cycle neighborhood if the neighborhood is located in a casualty prone area.
- *Ground level measures (e.g. elevation of ground level)*: the water depth is reduced by heightening the ground level. This measure is applicable in areas where the water depth can be reduced to a safe level. The measure can be combined with construction measures but will only be applicable to new developments.
- *Construction measures*: can be combined with measures to reduce the impact of pluvial flooding. The measures are only applicable to areas with limited water depths. It is not feasible to apply these measures to existing buildings.
- *Utility measures*: mainly to prevent damage due to chemical spill.

Reducing sensitivity by supporting event management:

- *Vital infrastructure (e.g. communication systems)*: (re) location of vital infrastructure such that damage is prevented and the accessibility during a flood is guaranteed.
- *Horizontal evacuation (outside of flooded area)*: providing accessible evacuation routes. This option is applicable for areas where large water depths and/or duration of flooding are expected and prediction time is long enough to evacuate the area.
- *Vertical evacuation (within the area)*: providing shelters, high buildings, high grounds within the flood prone area. This option is applicable for areas where smaller water depths and/or duration of flooding are expected or prediction time is too short to evacuate the area.

Table B.1 gives an overview of the spatial planning measures for water safety.

Table B.1 Overview of spatial measures for water safety

Measure group	**Applicable for areas with:**	**Reduction of:**	**Applicable on an urban scale**
Reducing exposure			
Embankments in combination with other functions		Damage, casualties	Yes / No
Compartimentalisation		Damage, casualties	Yes / No
Reducing sensitivity: Zoning and building regulations			
Construction measures (on buildings)	< water depth < flow velocity	Damage	Yes
Ground level measures (e.g. elevation of ground level)	< and <> water depth	Damage, casualties	Yes
Utility measures (e.g. prevention spreading of hazardous materials)	Flood prone area	Damage	Yes
Zoning	Flood prone areas	Damage, casualties	Yes / No
Reducing sensitivity: supporting event management			
Prevention of damage to and accessibility of (vital) infrastructure (e.g. communication system)		Damage, casualties	No
Horizontal evacuation: For spatial planning mainly evacuation routes	> water depth > duration > prediction time < flood extent	Casualties	No
Vertical evacuation: shelters, high buildings, high grounds	> water depth > duration > prediction time < flood extent	Casualties	Yes

The boundary between small and large water depth needs to be explored. Boundary will probably differ between measures. Effect of climate as well, if due to climate change certain areas shift from the category small to large water depth.

C Scenario sensitivity of the conclusions

Table C.1 Scenario sensitivity of general conclusions

	Socio-economic scenarios (CPB, 2004)	**Climate Scenarios** (KNMI, 2006)
High relevance of climate vulnerability	Valid for all scenarios. Especially for Strong Europe and Global Economy, because of increased sensitivity due to economic and population growth.	Valid for all scenarios. Marginally more for W and W+. W+ and G+ also get dryer summers with higher rainfall intensity (more extremes).

Table C.2 Scenario sensitivity of conclusions for water safety

	Socio-economic scenarios (CPB, 2004)	**Climate Scenarios** (KNMI, 2006)
Exposure to flooding for residential and industrial area	Valid for all scenarios. Scenarios do not have influence on conclusions.	Valid for all scenarios. Marginally more for W and W+, because of higher sea sea level rise.
Cultural heritage minimally exposed to flooding		
Flooding from regional water could be substantial on a local scale		
Effects of climate change on vulnerability of urban areas to flooding	Valid for all scenarios. Especially for Strong Europe and Global Economy, because of increased sensitivity due to economic and population growth.	
No regret measures can be achieved by coupling with measures which reduce pluvial flooding impact	Especially valid for Global Economy and Transatlantic Market scenarios, due to lack of effective environmental policy.	

Table C.3 Scenario sensitivity of conclusions for water nuisance

	Socio-economic scenarios (CPB, 2004)	**Climate Scenarios** (KNMI, 2006)
No strict relation found between urban typologies and water nuisance	Valid for all scenarios. Scenarios do not have influence on conclusions.	Valid for all scenarios.
Differentiate between frequent and extreme events		Valid for all scenarios. Especially for W+ and G+, because of more expected rainfall extremes. This leads to increased runoff.
Focus on downtown areas		Valid for all scenarios.
Groundwater nuisance may occur in every city		Valid for all scenarios. Especially for W+ and G+, because of more expected rainfall extremes and drought.
Though an increase of groundwater nuisance will occur, possibilities to overcome this are readily available		Valid for all scenarios.

Table C.4 Scenario sensitivity of conclusions for drought

	Socio-economic scenarios (CPB, 2004)	**Climate Scenarios** (KNMI, 2006)
Historical buildings are the urban functions that are most vulnerable for increase in drought caused by climate change	Valid for all scenarios. Scenarios do not have influence on conclusions.	In particular relevant for W+ and G+ scenarios in which significantly dryer summers occur compared to the W and G scenarios.
Land subsidence caused by drought will increase, though it is unknown to what extend this will damage urban functions		In particular relevant for W+ and G+ scenarios in which significantly dryer summers occur compared to the W and G scenarios.
The vulnerability of urban parks and trees to drought is generally limited		Valid for all scenarios.

Table C.5 Scenario sensitivity of conclusions for heat

	Socio-economic scenarios (CPB, 2004)	**Climate Scenarios** (KNMI, 2006)
Downtown areas are prone to heat stress; other areas show a large variability	Valid for all scenarios. Scenarios do not have influence on conclusions.	Valid for all scenarios. Marginally more for W and W+ because higher temperature increase of the average warmest summer day per year of 1-2C.
Use space wisely		Valid for all scenarios.
Differentiate between inside and outside		Valid for all scenarios.

Table C.6 Scenario sensitivity of conclusions for adaptive capacity and measures

	Socio-economic scenarios (CPB, 2004)	**Climate Scenarios** (KNMI, 2006)
Mainstreaming adaptation with urban renewal could lead to a significant reduction of vulnerability	Especially valid for Global Economy and Transatlantic Market scenarios, due to lack of effective environmental policy.	Independent to degree of climate change.
Selection of adaptation measures	Valid for all scenarios.	Valid for all scenarios. Faster change requires active adaptation in places where the system does not met safety standards.
Maximise the no-regret zone	Especially valid for Global Economy and Transatlantic Market scenarios, due to lack of effective environmental policy.	Valid for all scenarios.
Maximise linking with mitigation strategies	Likely to be most effective in Strong Europe and Regional Communities scenarios, because of effective environmental policy.	Valid for all scenarios.
Stakeholder involvement	Private sector plays important role in Global Economy and Transatlantic Market scenarios. It needs to be encouraged to take its responsibility. Public sector in Strong Europe and Regional Communities scenarios.	Independent to degree of climate change.

Table C.7 Scenario sensitivity of conclusions for policy

	Socio-economic scenarios (CPB, 2004)	**Climate Scenarios** (KNMI, 2006)
Existing policy recognizes relevance and urgency, but lacks operationalisation	Especially true for Global Economy and Transatlantic Market scenarios, because lack of effective environmental policy.	Independent to degree of climate change.

CLIMATE PROOF NETHERLANDS

This report is part of a series of 'building blocks' that were completed in the project 'Climate Proofing the Netherlands' (KBNL). The aim of this project is to give insight into the effects of different policy options the Dutch government has regarding climate change adaptation. These options aim for an integrated approach, including all sectors involved in sustainable, climate proof planning. This means that the possibilities of integrating adaptation with other (existing) policy and socio-economic development in the long term should always be taken into account. The building blocks in this series are:

- Rural areas
- Urban areas
- Systems analysis
- Legal and policy aspects of climate change adaptation
- Health
- Water system
- Networks

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