Experimental ditches for ecotoxicological experiments and eutrophication research under natural conditions

A technical survey

J. Drent
K. Kersting

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ABSTRACT

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With the construction of twenty experimental ditches human impact on ecosystems can be studied under controllable but real-field situations and natural conditions. The facility allows ecotoxicological experiments and eutrophication research. The plant has been designed with maximum flexibility for future studies. Supply and discharge of water are controlled by tipping-buckets and pumps respectively and are registered automatically by a datalogger connected with a personal computer. Necessary meteorological data are recorded in an automatic weather station of Campbell Scientific Ltd (Shepshed, Leicestershire, UK). Average evaporation for the period Oct. 1990 to Oct. 1991 was 1.80 mm/d with a standard deviation of 0.10 mm/d. This small standard deviation and the reliability of the calculated evaporation indicates that the measured precipitation, supply and discharge can also be used for the reliable calculation of nutrient balances. Acidity, oxygen concentration and water temperature are measured continuously in the ditches with sensors of WTW (Weilheim, Germany). Most oxygen electrodes have been operated continuously during a period of almost two years without the membranes or the electrolyte needing to be replaced. The pH sensors had served generally for about one year of continuous use before they had to be replaced. The data are retrieved from a datalogger system using personal computers provided with modems and specific software. The experiments in the ditches are in full progress and the results will be published separately.

Keywords: mesocosms, pesticides, eutrophication, oxygen, pH and temperature sensors.

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DLO The Winand Staring Centre is continuing the research of: Institute for Land and Water Management Research (ICW), Institute for Pesticide Research, Environment Division (IOB), Dorschkamp Research Institute for Forestry and Landscape Planning, Division of Landscape Planning (LB), and Soil Survey Institute (STIBOKA).

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PREFACE

Studying human impact on surface water ecosystems under natural conditions is only possible in well controllable but real-field systems. For that reason the DLO Winand Staring Centre for Integrated Land, Soil and Water Research has constructed twenty experimental ditches for ecological experiments and eutrophication research with finances of the Directorate for Agricultural Research of the Ministry of Agriculture, Nature Management en Fisheries and with fonds of the Toxicological Research Programme of the Ministry of Education and Research.

Because of common interests, the DLO Winand Staring Centre for Integrated Land, Soil and Water Research, the DLO Institute for Forestry and Nature Research and the Section Water Quality Management of the Department of Nature Conservation of the Wageningen Agricultural University agreed to collaborate in the research programmes concerning the experimental ditches. A management committee approves the working plans, assesses the annual budget and spreads the running costs over projects and participitants.

The experiments in the ditches are in full progress and the results will be published seperately.

SUMMARY

Two major research topics called for the need of an experimental facility of ditches to be used for investigations under natural conditions. First the use of pesticides in agriculture and horticulture is controlled by regulations. The responsible authorities want to know the risk of unwanted side-effects. Till now this risks are estimated on basis of the physico-chemical properties of a pesticide and on laboratory tests on single species. The usefulness of this hazard evaluation procedure is unknown. To improve risk prediction mesocosm studies are necessary. Second the effects of the decrease of external input of phosphate and nitrogen on the reduction of the eutrophication of surface waters can not be studied well under laboratory conditions because ecological systems are too complicated. Therefore a well controllable natural system is a good alternative.

With the construction of twenty experimental ditches human impact on ecosystems can be studied under controllable but real-field situations and natural conditions. The facility allows for ecotoxicological experiments and eutrophication research. The plant is designed with maximum flexibility for future studies.

Supply and discharge of water are controlled by tipping-buckets and pumps respectively and are registered automatically by a datalogger connected with a personal computer. Necessary meteorological data are recorded in an automatic weather station of Campbell Scientific Ltd. (Shepshed, Leicestershire, UK). Average evaporation for the period Oct. 1990 to Oct. 1991 is 1.80 $mm.day^{-1}$ with a standard deviation of 0.10 $mm.day^{-1}$. This small standard deviation and the reliability of the calculated evaporation indicates that the measured precipitation, supply and discharge can also be used for the reliable calculation of nutrient balances. Acidity, oxygen-concentration and water temperature are measured continuously in the ditches with sensors of WTW (Weilheim, Germany). Most oxygen electrodes have been operated continuously during a period of almost two year without the membranes or the electrolyte needing to be replaced. The pH sensors have served generally for about one year of continuous use before they had to be replaced. The data are retrieved from a datalogger system using personal computers provided with modems and specific software.

At present two research projects are being carried out. In twelve ditches with a silty sediment pesticide dissipitation, mixing and persistence are studied as well as subsequent direct and indirect effects and ecosystem recovery. In the eight other ditches the effects of nutrient loading is studied. Four of these eutrophication ditches have the same silty sediment as the ecotoxicology ditches, whereas four had a bare sandy bottom from the start.

The experiments are is full progress and the results will be published seperately.

1 INTRODUCTION

Human impact on ecosystems can be studied in the field or in the laboratory. In the field experimentation is complicated because of non-homogeneity, uncontrollable hydrological conditions and therefore lack of replicability. In the laboratory on the other hand experimentation lacks pollutant realism and at best limited authentic biocoenosis. The lack of ecological integrity hampers the extrapolation of laboratory data. There is clearly a need for experimental systems so that human impact on ecosystems can be studied under almost natural conditions (Odum, 1984).

In the Netherlands drainage ditches with a total estimated length of 300 000 km (Higler, 1989) represent an important category of aquatic ecosystems. These ditches are especially important in agricultural areas; the impact of current agricultural techniques, for example the use of pesticides and fertilizers, on these aquatic ecosystems are a major field of study. The facility described in this paper was constructed in order to create experimental systems that resemble drainage ditches as closely as possible.

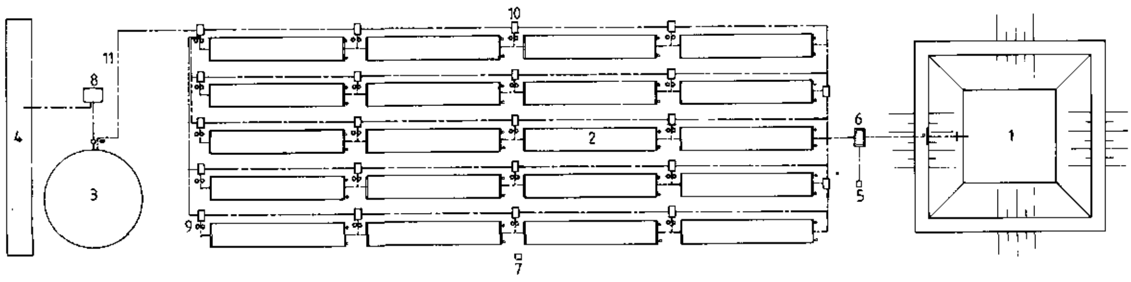
The design and instrumentation of the experimental ditches have been developed by two Institutes: DLO The Winand Staring Centre for Integrated Land, Soil and Water Research and DLO Institute for Forestry and Nature Research.

Two major research topics called for the need of an experimental facility of ditches to be used for investigations under natural conditions.

1 The use of pesticides in agriculture can result in active ingredients being dispersed into aquatic ecosystems. For regulatory purposes risk estimates are based upon physico-chemical properties of the pesticide and on laboratory single species toxicity tests. To improve risk prediction mesocosm studies might be necessary. To evaluate the fate and potential effects of pesticide dissipation, a long term simulated field study can be carried out in the experimental ditches for testing under conditions of natural shallow ponds. Ecological and physico-chemical properties can be monitored regularly at several levels of biological organization, including fish. Recovery can be described at the level of single species and taxonomical groups (e.g. zooplankton, macroinvertebrates) by comparing normal variation between controls with that between treatments before and after application of the pesticide.
2 Reducing eutrophication of surface waters is possible by decreasing the external input of phosphate and nitrogen. The effects of this decrease depend on the internal load from bottom sludge. Ecological systems are in fact too complicated to test under laboratory conditions. On the other hand, field experiments are often affected by the uncertainty of water and nutrient budgets. Therefore a well controllable natural system is a good alternative.

The research facility has been constructed on the Sinderhoeve experimental station, Renkum, the Netherlands. Supply and discharge of water, pesticides and nutrients can be manipulated. General physical parameters such as oxygen concentration, acidity and water temperature are constantly recorded.

This technical survey gives an outline of the plant construction, the measuring instruments and the data registration system.



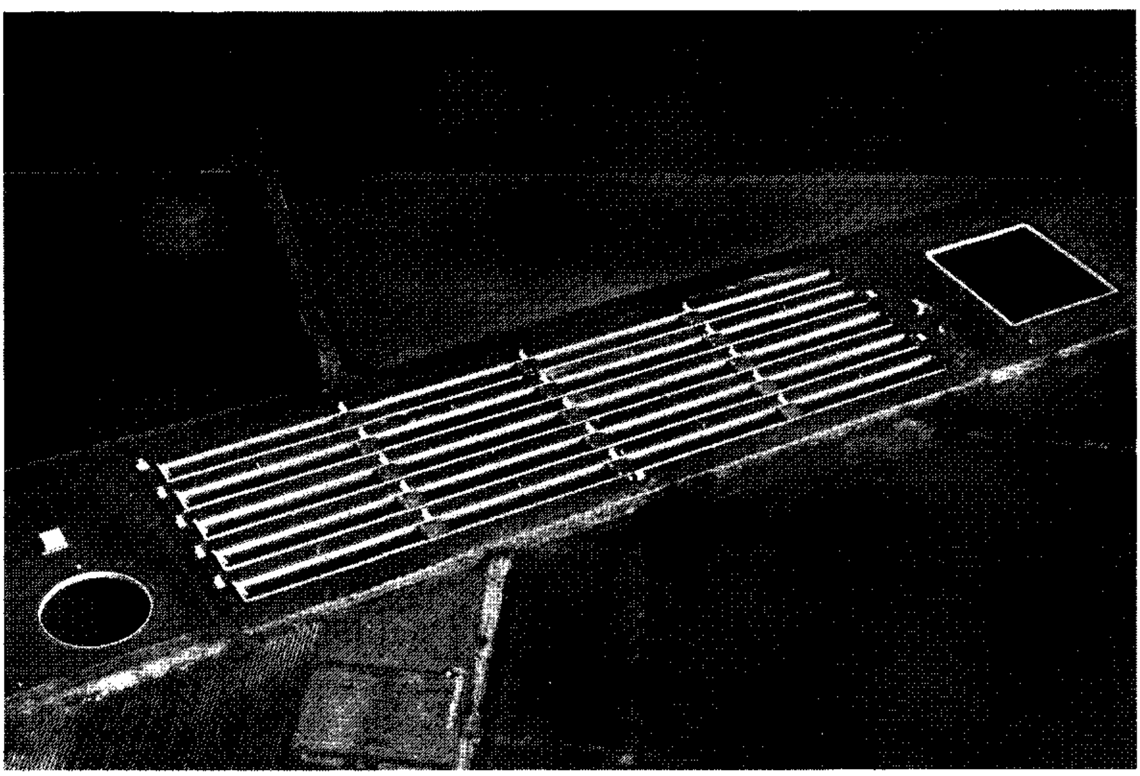


Fig. 1 Scheme and aerial photo of the experimental ditches

2 CONSTRUCTION

The plant consists of 20 uniform ditches (Figure 1), each 40 m long, which can all be interconnected. The water depth can be varied from 0.25 m to 0.75 m. The width at the top of the bottom sediment is 1.60 m. Depending on the water depth, the width at the surface varies between 2.35 m and 3.85 m. The volume varies between 20 m^3 and 80 m^3. The ditches can be used independently of each other as stagnant systems or as flow-through systems. The bottom sediment in 16 ditches is silty clay and is collected from a mesotrophic aquatic ecosystem; four ditches have a sandy bottom. Both sediments are uncontaminated and have low nutrient contents. The bottom sediment was introduced in a layer of 0.25 m as a substrate and as a source of benthic and pelagic organisms.

The ditches (Figure 2) are lined with watertight, non-toxic PVC to prevent uncontrolled losses to the groundwater. On the top of the PVC a rough cover layer has been laid consisting of an open-structured nylon material with a 95% open space filled with fine gravel to act as a settling place for vegetation. The bottom sediment and the filter sand are separated by open-structured nylon webbing. To prevent unwanted losses of water if the first protection layer is damaged, a second watertight PVC layer has been used. The drainage pipe between the two layers serves only as an inspection function in this context.

The supply and the discharge systems of the experimental ditches has been constructed so that different hydrological conditions can be simulated. The supply and the discharge of the water are controlled by tipping-buckets and pumps respectively.

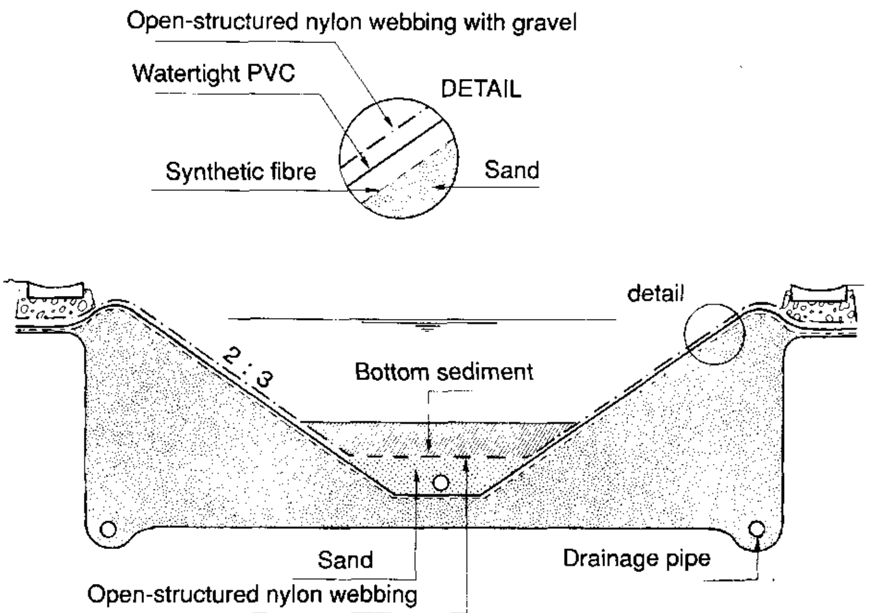


Fig. 2 Transverse section of an experimental ditch. The inset shows the different protection layers in more detail

Using the drainage pipe in the filter sand of the ditches it is possible to simulate the infiltration of surface water into the bottom sediment and also the seepage from groundwater. Figure 3 gives a longitudinal section of ditches, pipes and fittings.

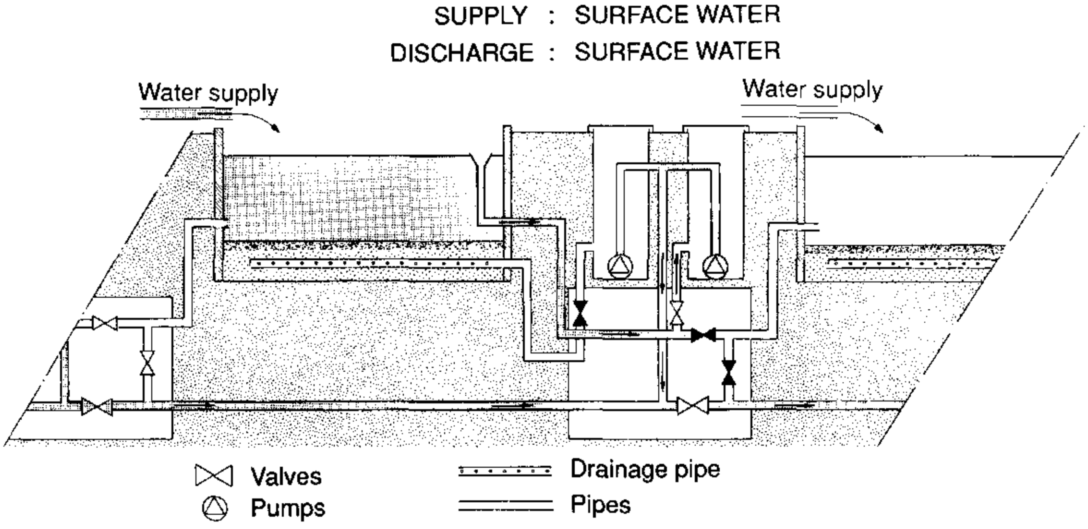


Fig. 3 Longitudinal section of ditches, pipes and fittings of the experimental ditches

Using the correct valves the following options are possible:

1 The supply of surface water by tipping-buckets and discharging as surface water over a funnel to a pumping unit. The residence time depends on the supply velocity and can be 10 days or more. The processes taking place in the water and in the boundary layer of water and sediment can then be studied.

2 The supply of surface water by tipping-buckets and discharging as drainage water after infiltration into the bottom sludge. For this purpose, the drainage pipe in the filter sand is used. The drainage water is discharged by a second pumping unit. In this option biological and chemical processes in the sediment during infiltration of surface water can be followed as a function of residence time.

3 The supply of seepage water and the discharge of surface water. In this option the drainage pipe is used to simulate seepage situations. Using this option the different processes can be studied in relation to residence time and quality of seepage water.

4 For specific experiments it will be necessary to establish the same chemical and biological conditions in the ditches used. This homogeneous situation can be realized by circulating the water between ditches.

The supply water can be withdrawn from a local deep well or from the supply reservoir (35 m x 35 m, silty clay sediment from the same source as in the ditches, originally filled with deep well water and left to develop a typical pond/ditch community). To compensate for evaporation and to maintain a constant water level during the experiment water will be let in from the deep well. The water from the deep well has a low concentration of minerals and nutrients. The concentrations can be varied by adding nutrients.

The discharged water is collected in a reservoir. This water will eventually be infiltrated into a basin after purification through a charcoal filter.

To prevent the unwanted invasion of waterfowl the ditches and supply reservoir are covered with a net with side and upper meshes of 0.07 and 0.10 m respectively.

3 MEASURING INSTRUMENTS

3.1 Weather station

Air temperature, relative humidity, wind speed, wind direction, irradiance and precipitation are measured continuously in an automatic weather station of Campbell Scientific Ltd (Shepshed, Leicestershire, UK).

The air temperature measurement is achieved using a Fenwal Electronics UUT51J1 precision thermister. The overall accuracy is ± 0.2 °C over a range of -33 °C to +48 °C.

Relative humidity is measured through changes in the capacitance of a metal plate capacitor with a permeable top plate and dielectric. The top plate is'cracked chromium', being a very thin evaporated layer that has been stretched and cracked. The dielectric absorbs water vapour, the amount absorbed depending on the ambient relative humidity. The sensor is manufactured under CEA licence, France.

A switching anemometer type A100R (Vector Instruments Ltd, UK) is used for wind measurements with an accuracy of 1%. A W200P wind vane (Vector Instruments Ltd, UK) measures wind direction. The wind vane incorporates a 358° micro-torque potentiometer. The 2° gap is filled to ensure smooth operation.

Irradiance is measured with a silicon cell pyranometer type SP 1110 (Sky Instruments Ltd, Wales).

Precipitation is measured by an ARG100 rain gauge, manufactured by Environmental Measurements Ltd (Oxford, UK).

3.2 Instrumentation for water balances

3.2.1 Precipitation

The rain gauge (0.25 m diameter) of the Weather Station operates on the tipping-bucket principle and provides a switch output. Each tip corresponds to 0.2 mm of rain. The instrument is sited in a pit with the top of the funnel at surface level. Between the funnel and the surrounding ground surface an open area of about 0.1 m width has been constructed to prevent any splash into the funnel. At fortnightly intervals a measured quantity of water is slowly poured through the gauge and compared with the counted values. Figure 4 gives the result of these regular checks. The correlation between measured and registered values is calculated by linear regression (r^2 = 0.995).

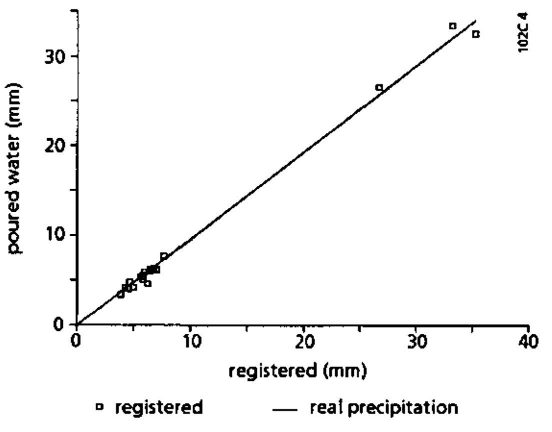


***Fig. 4** Calibration of the ARG100 rain gauge by pouring a measured quantity of water. Real precipitation = 0.9651 * registered precipitation (r^2 = 0.995)*

3.2.2 Supply

In connection with different kinds of experiments the water level in the ditches must be constant. Supply water, necessary in dry periods, is withdrawn from the supply reservoir or from the local deep well. As already mentioned tipping-buckets (Tumakon, the Netherlands) are used to measure the supplied quantity of water. The content (about 0.001 m^3) of each tipping-bucket is calibrated by hand.

3.2.3 Discharge

In times of water surplus in the ditches, the water flows over a constant level funnel to a pumping unit. The pump (ABS, type MF-402D) is switched by level probes (Electromatic, type VNY). Once a pump has been started it continues until the pump pit has been emptied. Inflow from the ditches during the pumping action is negligible. Discharge can be calculated by multiplying the content by the number of pump actions. The content of each pump unit (about 0.200 m^3) is calibrated by hand. During pumping a magnetic valve type FIP SI22 DN10 (Vink, the Netherlands) is opened for a short time to obtain a proportional sample of the discharge.

3.2.4 Evaporation

Evaporation is normally calculated as a rest term of the water balance: precipitation plus supply minus discharge. The consequence is that the errors in the measured terms of the balance equation accumulate in the evaporation. An estimate of error is obtained by measuring the evaporation using an evaporation pan in one ditch. The water level in the pan is measured by hand with a nonius micrometer. The internal measuring part is separated from the outside water with a concentric ring of 0.2 m to avoid splash water. This ring has a raised border and remains in open contact with the surface water. The measured evaporation during the period June — September 1991 was 342 mm and quite close to the calculated one of 368 mm.

The difference between measured and calculated evaporation partly results from evaporation from the sides of the ditch and is partly due to small measuring errors in the terms of the balance. These results mean that 93% of the evaporation calculated with the water balance terms is evaporation of surface water.

3.3 Instrumentation for oxygen, pH and water temperature

The continuous measurements are performed in the middle of each ditch. Two oxygen sensors WTW (Weilheim, Germany) type Trioxmatic 600-DU and 1 pH sensor WTW type SensoLyt AVK/T are clamped to a vertical rod. This rod is moved laterally by a screenwiper-like construction driven by a Berger Lahr (Lahr, Germany) type RSM63/8NcG 24/50-G=5 $r.min^{-1}$ synchronous motor. The rod travels about 30 cm to and fro, which, with a frequency of five rotations per minute, gives a velocity of about 5 cm/s through the water. This is enough to give a precision for the oxygen measurement of more than 1%. This precision with a low water current is possible by using a 50 m membrane and a small gold electrode. The thick membrane also makes the electrode insensitive to fouling. The oxygen sensors are positioned at 10 and 40 cm depth and the pH sensor at 25 cm depth. Three temperature sensors (WTW TFK 150) are fixed to a standing rod at 10, 25, and 40 cm below the surface at a maximum water depth of 50 cm. All construction material is made of stainless steel.

The oxygen and pH sensors are connected to a WTW type OXI-219 oxygen indicating unit and a WTW type pH-219 pH indicating unit respectively. The temperature sensors are attached to a connector strip. All sensors are coupled via Campbell Scientific Ltd model AM32B multiplexers to a Campbell Scientific Ltd model CR10 datalogger. The WTW OXI-219 and pH-219 units provide a 0 to 20 mA current output which is measured across precision temperature-insensitive resistors of 100 Ω. The WTW TK 150 temperature sensors are thermistor type sensors that are measured in a half bridge with a 10 kΩ precision resistor as reference and a reference voltage of 2.5 V. In addition an Aandera (Bergen, Norway) model 2810 Air Pressure Sensor and a Licor (Lincoln, Nebraska, USA) model 190SB Quantum Sensor are connected to the datalogger.

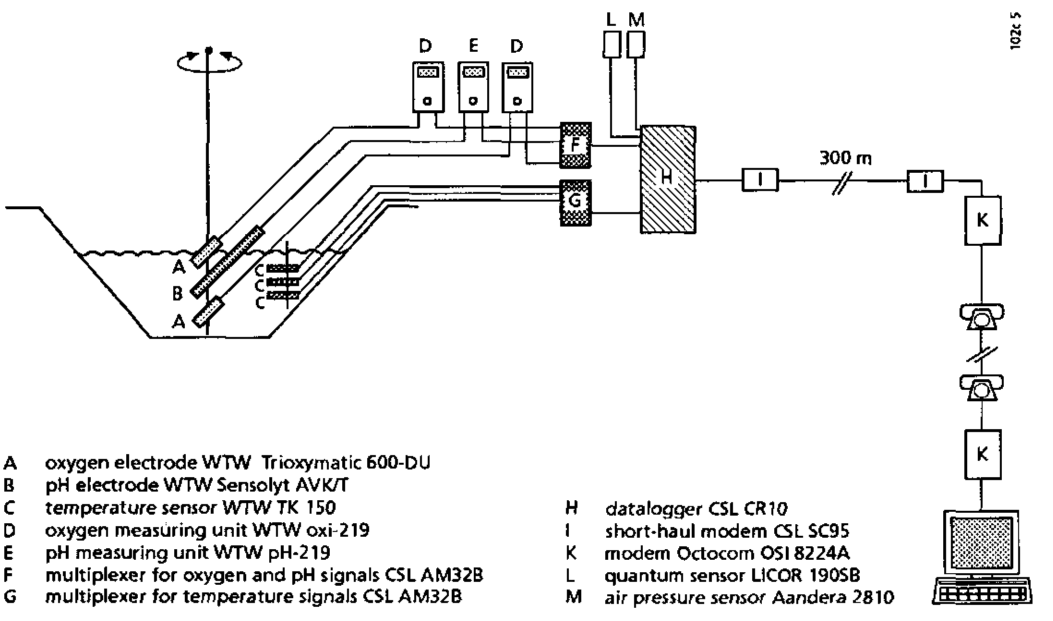


***Fig. 5** Outline of the measuring instruments and the wiring of the complete system from measuring points to data registration*

4 DATA RETRIEVAL

4.1 Supply and discharge

There is one datalogger system installed for both the supply and discharge of water. An approach switch Bauform IG (Germany) on each tipping-bucket is connected to a channel address of an HP 44721A 16-channel card in an HP 3852A Mainframe. Each electric pulse is counted in that address. Each time the pump in the discharge unit starts an electric signal goes to another channel address in the same HP 44721A card. For all sensors seven cards are available. The HP 3852A datalogger is connected via a set of HP-IB extenders, model HP-IB 37204A, to an HP Vectra 45970A personal computer. The Vectra retrieves daily the counts in the different addresses.

4.2 Oxygen, pH and temperature

There are two separate datalogger systems installed for oxygen, pH and water temperature, one for twelve ditches used for ecotoxicological research and one system for eight ditches for eutrophication studies. A third datalogger is part of the Campbell Scientific Ltd Weather Station. The three dataloggers are connected via a set of Campbell Scientific Ltd model SC95 short haul modems to Octocom (Wilmington, MA, USA) model OSI8224A Hayes compatible modems and the public telephone network. The data are automatically retrieved daily using a personal computer provided with an Octocom modem and the Campbell Scientific Ltd PC208 software package. An outline of the wiring of the complete system is shown in Figure 5.

The sensors are scanned every 30 seconds and the 15 minutes' averages are stored in the memory of the datalogger. The memory can store almost 30 000 data points, which is enough for 3, 5, or 26 days of measurements in the twelve toxicology ditches, the eight eutrophication ditches, and the weather station respectively. As extra security, Campbell Scientific Ltd model SM192 Solid State Storage Modules are coupled to the dataloggers for the measurements in the ditches increasing the storage capacity to 126 000 data points.

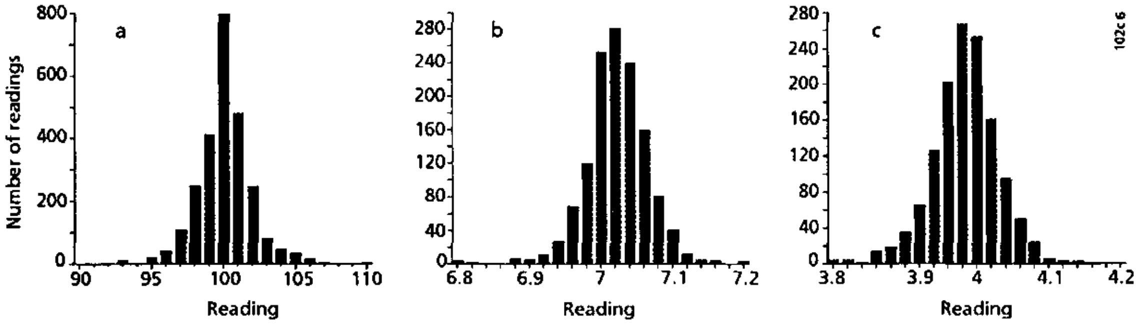


***Fig. 6** Calibration results expressed as frequency distribution of the readings prior to adjustment. The results are based on 85 calibrations of the 40 oxygen electrodes and the 20 pH electrodes*

a: oxygen (reading 100% means no adjustment necessary)

b: pH 7 buffer (reading 7 means no adjustment necessary)

c: pH 4 buffer after adjustment to pH 7 (reading 4 means no adjustment necessary)

5 PERFORMANCE

5.1 Physico-chemical variables

Full-scale measurements were started in March 1989. During the winter of 1989-1990 the sensors were removed for two months during which time some modifications to the installation were made. From February 1990 until January 1992 all ditches were monitored. The oxygen and pH sensors are calibrated either once a week or once a fortnight. The pH electrodes are adjusted to pH 7 and pH 4 with buffers. The oxygen electrodes are adjusted to 100% saturation after equilibration in air for 15 minutes. Before calibration the pH glass electrode and membranes of the oxygen sensors are cleaned with paper tissue dampened with distilled water.

During the two years of continuous operation a total of about 2600 calibrations was made. The frequency distributions of the equilibrium values before adjustment are shown in Figure 6.

For the oxygen electrodes a narrow distribution was found. In 64% of cases the obtained saturation reading was accurate to 1% after functioning during the inter-calibration period (1 to 2 weeks). Aberrations of ≤2% and ≤5% were obtained in 82% and 96% of the calibrations respectively. Most oxygen electrodes served the complete period of almost two years without the membranes or the electrolyte needing to be replaced. The frequency distribution is symmetrical, approximately 100%, indicating that there is no systematic drift.

The pH sensors generally served for about one year of continuous use before they had to be replaced. The frequency distribution of the pH 7 values is slightly skewed to the right (Figure 6b) indicating a systematic change during the intervals between calibrations. The asymmetry potential needed to be adjusted regularly, until after about one year it was no longer possible to obtain the pH 7 reading and the electrode had to be replaced.

5.2 Water balance

The frequency of registering precipitation, and the supply and discharge of water allows a water balance to be calculated for each ditch daily, weekly or any other period. In Table 1 the weekly values are counted for an annual survey for each ditch. Average evaporation for the period Oct. 1990 to Oct. 1991 is 1.80 mm/d with a standard deviation of 0.10 mm/d. This small standard deviation and the reliability of the calculated evaporation indicates that the measured precipitation, supply and discharge can also be used for the reliable calculation of nutrient balances.

Table Supply, discharge and evaporation per ditch during the period Oct. 1990 to Oct. 1991. Precipitation per ditch is 148.31 m³. Average evaporation: 1.80 mm/d, standard deviation 0.10 mm/d

Ditch nr.	Supply (m^3)	Discharge (m^3)	Evaporation	
			(m^3)	(mm/d)
1	34.47	88.81	93.98	1.95
2	27.72	82.81	93.22	1.93
3	28.71	86.87	90.15	1.87
4	29.18	93.71	83.78	1.74
5	33.46	95.85	85.92	1.78
6	30.85	94.69	84.48	1.75
7	29.46	89.42	88.35	1.83
8	28.00	94.42	81.89	1.70
9	32.80	96.80	84.32	1.75
10	24.63	93.21	79.74	1.66
11	30.14	95.74	82.71	1.72
12	30.14	96.17	82.28	1.71
13	35.24	97.71	85.84	1.78
14	34.80	86.29	96.82	2.01
15	30.99	96.66	82.65	1.72
16	42.76	104.38	86.69	1.80
17	36.16	93.48	90.99	1.89
18	33.07	94.54	86.84	1.80
19	34.20	89.68	92.84	1.93
20	26.13	94.18	80.26	1.67

6 CLOSING REMARKS

At present two research projects are being carried out. In twelve ditches with a silty sediment pesticide dissipation, mixing and persistence are studied as well as the subsequent direct and indirect effects and ecosystem recovery. In the eight other ditches the effect of nutrient loading is studied. Four of these eutrophication ditches have the same silty clay sediment as the ecotoxicology ditches, whereas four had a bare sandy bottom from the start. The experiments are in full progress and the results will be published separately.

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