CHALMERS UNIVERSITY OF TECHNOLOGY

URBAN GEOHYDROLOGY
RESEARCH GROUP

Departments of:
Geology
Geotechnical Engineering
Hydraulics
Water Supply and Sewerage

URBAN STORM WATER RESEARCH IN SWEDEN

VIKTOR ARNELL
JAN FALK
PER-ARNE MALMQUIST

Report No 19

GÖTEBORG 1977

CHALMERS UNIVERSITY OF TECHNOLOGY

URBAN GEOHYDROLOGY
RESEARCH GROUP

Departments of:

Geology

Geotechnical Engineering

Hydraulics

Water Supply and Sewerage

URBAN STORM WATER RESEARCH IN SWEDEN

PAPER PRESENTED AT THE ENGINEERING FOUNDATION CONFERENCE: "INSTRUMENTATION AND ANALYSIS OF URBAN STORM WATER DATA - QUANTITY AND QUALITY" IN EASTON MARYLAND, NOVEMBER 28 - DECEMBER 3, 1976.

VIKTOR ARNELL

JAN FALK

PER-ARNE MALMQUIST

Address:
Urban Geohydrology
Research Group
Fack
402 20 GÖTEBORG

Report No 19

GÖTEBORG 1977

CONTENT

ABSTRACT

Projects concerning urban drainage research and mathematical modelling are in principal carried out in three areas:

a) The effect of urbanization on the hydrological environment.

b) Analysis and design of storm sewer systems.

c) Storm water pollution and the dependence of different sources of pollution.

Chalmers University of Technology is studying planning and design of storm sewers as well as storm water pollution. Investigations are carried out of different storm water infiltration plants. Field investigations are being made in ten areas in Southern Sweden. The measurement program includes rainfall and runoff (quantity and quality). The data is used for statistical analysis and mathematical modeling with regard to both quantity and quality aspects. The Institute of Technology, the University of Lund, is engaged in research on different types of surface runoff. Measurements are now being taken on rainfall-runoff in a Lund housing area. A mathematical non-linear reservoir model is being tested with good results. Studies are made of the water budget of urban areas to summarize the draw-backs of water management in such areas and to specify a research program for the continued urban hydrological research.

URBAN DRAINAGE RESEARCH AND MATHEMATICAL MODELING IN SWEDEN.

Background

Studies of Swedish urban drainage began in the sixties. Between 1950 and 1965 there had been no research in urban hydrology at all. With the start of the International Hydrology Decade (IHD) a few projects dealing with the effect of urbanization on the hydrological environment were initiated. These projects were financed by the Swedish Natural Science Research Council. A few years later the Swedish Council for Building Research began sponsoring projects on urban storm sewer systems and pollution on the basis of the rising investment and maintenance costs in storm sewer systems together with the relative increase of storm water pollution compared with the discharge of purified sewage into the receiving waters. A review of Urban Hydrological Research in Sweden is presented in Technical Memorandum No IHP-7 (Lindh, 1976).

Current projects

In principal, projects are being carried out in three areas.

1. The effect of urbanization on the hydrological environment.
2. Analysis and design of storm sewer systems.
3. Storm water pollution and the dependence of different sources of pollution

At Chalmers University of Technology, Gothenburg, a research group is studying both the design of storm sewer systems and the pollution of storm water through a combination of different projects and active cooperation.

The effects of urbanization are being studied in Stockholm at the Royal Institute of Technology, who have a research basin, Verkaån, with an area of 116 km^2, comprising 44 % forest and 52 % open country (Nilsson, 1973). The measuring program includes registration of runoff, precipitation, groundwater table, soil moisture, water quality etc. By comparing the water balance with nearby urbanized basins it is possible to study the effect of urbanization.

The University of Lund has two research areas. The first is Värpinge, comprising 3 km^2 of farmland. This basin is equipped with a meteorological station, runoff instruments, groundwater level and soil water content. The second area is Sturup, measuring 40 km^2, which is Southern Swedens main airport. The measurements here are focused on the variations in the groundwater and soil water storages as a result of paving of the airfield.

Urban rainfall-runoff studies in connection with the design of storm sewers are carried out at various locations in Sweden. At Chalmers University of Technology Gothenburg, there are several current projects dealing with these problems. One project is concerned with analysis of rainfall data for the design of sewer systems, especially with the help of mathematical models. Different sewer design methods are studied and a mathematical runoff model has been developed for the design of sewers (Arnell & Lyngfelt, 1976). Rainfall-runoff measurements are carried out in ten areas in Gothenburg and Linköping in cooperation with local water and sewage works. In these areas, there are also equipments for water sampling. Hydraulics in channels and storm sewers are being studied and a mathematical model developed, solving the complete Saint-Venant equations for both pressurized and free surface flows (Sjöberg, 1976). In one test area in Gothenburg, experiments are carried out with infiltration of rain water primarily to keep the piezometric head high in the underlying clay, but also to retain the storm water (Cederwall & Holmstrand, 1976).

The University of Lund group is engaged in research on different types of surface runoff. Runoff from a small asphaltic area has been measured (Falk & Niemczynowics, 1976) and measurements are now being taken on rainfall-runoff in a Lund housing area. A mathematical non-linear resevoir model is being tested with good results. Some experiments with a laboratory rainfall-runoff model have also been made.

At the Institute of Technology in Stockholm a project concerning the hydraulics of stormoverflows has just been started.

In the north of Sweden, the design flows appear during the cold season. Runoff from this period, from snow melt in particular, is therefore studied at the University of Luleå.

Storm water pollution is studied at Chalmers University of Technology in Gothenburg. The variation of pollution during separate storms has been examined in two areas in Gothenburg (Malmquist & Svensson, 1975). Flow-proportional water samples are at present being taken in the previously mentioned areas in Gothenburg and Linköping. The chemical composition is compared with material corrosion and atmospheric fall-out measured in the research basins. In the near future, some mathematical modelings of storm water pollution will be made as well as an analysis of separate and combined sewers.

STORM WATER RESEARCH AT CHALMERS UNIVERSITY OF TECHNOLOGY.

Purpose of the Research

The basic aims of the urban storm water research at Chalmers University of Technology are:

1. To improve the methods and knowledge of storm sewer systems design.
2. To investigate the character and origin of the storm water pollutants in order to improve the decisionmaking from environmental and economic points of view.

Current Parts of the Project

1. Analyses of different design methods.
2. Development and testing of a mathematical rainfall-runoff model.
3. Evaluation and analysis of rainfall and runoff data for design purposes.
4. Studies of the character and origin of the storm water pollutants.
5. Development and testing of a mathematical storm water quality model, based on the pollutant sources.
6. Studies of the water balance and the total water pollutant mass flows in an urban area.
7. Tests and analyses of different mathematical models for the planning of urban storm sewer systems.
8. Investigations of the performance of different storm water infiltration plants.

Research Basins

Field investigations are now being carried out by Chalmers in ten areas in Southern Sweden in cooperation with local water and sewage works. All these areas have separate sewer systems.

1. Bergsjön (Mellbyleden), Gothenburg. Area 0.15 km^2.
   Land use: Apartment complexes.
   Studies of: Rainfall and runoff (quantity and quality), pollutant sources.
2. Bergsjösvängen, Gothenburg. Area: 0,05 km^2.
   Land use: Single-family houses.
   Studies of: Rainfall and runoff (quantity and quality), pollutant sources.

3. Floda (30 km north-east of Gothenburg). Area: 0.18 km^2.
Land use: Single-family houses.
Studies of: Rainfall and runoff (quantity and quality), pollutant sources.

4. Vegagatan, Gothenburg. Area: 0.06 km^2.
Land use: Apartment complexes and offices.
Studies of: Rainfall and runoff (quantity and quality), pollutant sources.

5. Linköping 1. (180 km south of Stockholm). Area: 2.0 km^2.
Land use: Mixed housing and commercial buildings.
Studies of: Rainfall and runoff (quantity and quality).

6. Linköping 2. (located within Linköping 1). Area: 0.22 km^2.
Land use: Single-family houses.
Studies of: Rainfall and runoff (quantity and quality).

7. Linköping 3. (located within Linköping 1). Area 0.04 km^2.
Land use: Apartment complexes.
Studies of: Rainfall and runoff (quantity and quality).

8. Torslanda (20 km west of Gothenburg). Area: 2.1 km^2.
Land use: Mixed housing and industrial buildings.
Studies of: Water balance, pollutant mass flows, performance of the urban water systems.

9. Bratthammar, Gothenburg. Area: 0.07 km^2.
Land use: Single-family houses.
Studies of: Storm water infiltration.

10. Halmstad (200 km south of Gothenburg). Area: 0.02 km^2.
Land use: Single-family houses.
Studies of: Storm water infiltration.

Criteria for the Choice of Investigation Areas

- The areas must be typical of the Swedish way of planning, building and maintenance.
- Different types of land use, topography, geology and environmental surroundings should be included.
- The areas must be small enough to facilitate instrumentation, analyses and mapping and be large enough to give general output data.
- The pipe sewer system must be in good conditions and the structure well known.

Instrumentation

A. Instrumentation for rainfall measurements.

Rainfall is measured in all the investigation areas. In all areas except Linköping the rain-gauges are rain-intensity instruments of the siphon type with registration on diagram paper.

In the Linköping 3 area the rain-gauge is of the tipping-bucket type with registration on a magnetic tape. In the Bergsjön area there is also a rain-gauge of the tipping-bucket type, teletransmitting its data to a central registration station. There is one gauge in each area, except in Linköping 1, where three gauges are installed. It is possible to evaluate the precipitation in 1/10 of a mm every second minute for the siphon-type instruments.

B. Instrumentation for runoff measurements.

Runoff measurements are carried out by means of triangular weirs of different types. In two areas measuring dams have been built downstream from the sewer outfall. In the other areas the weirs are located in manholes in the sewer system. The manholes are chosen at sites with satisfactory slopes. In three places the manholes were exchanged for manholes of a special size to get satisfactory flow conditions (see fig. 1). The water level is measured by sonic or ultrasonic sensors in all locations. Calibration facilities are installed. In the areas 1-4, the signals are after linearisation sent by telephone circuit to the University for punching on paper tape (see fig. 2). The time interval, which is controlled by the water level, is one minute for rainy periods and one hour for periods between rainfalls. The water sampling equipment is controlled by the linearised signal.

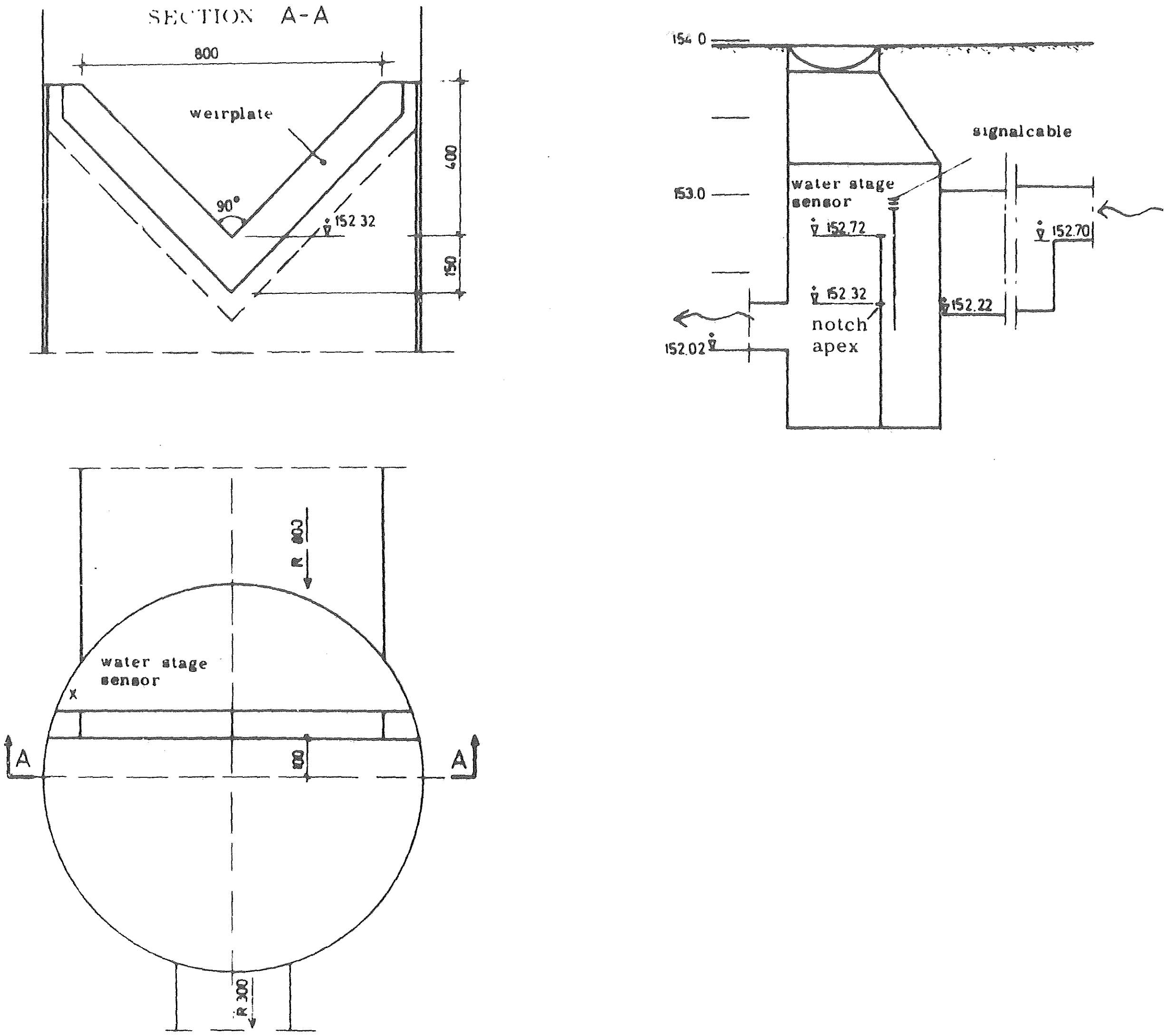

Fig. 1. Runoff measuring station with a triangular weir located in a manhole.

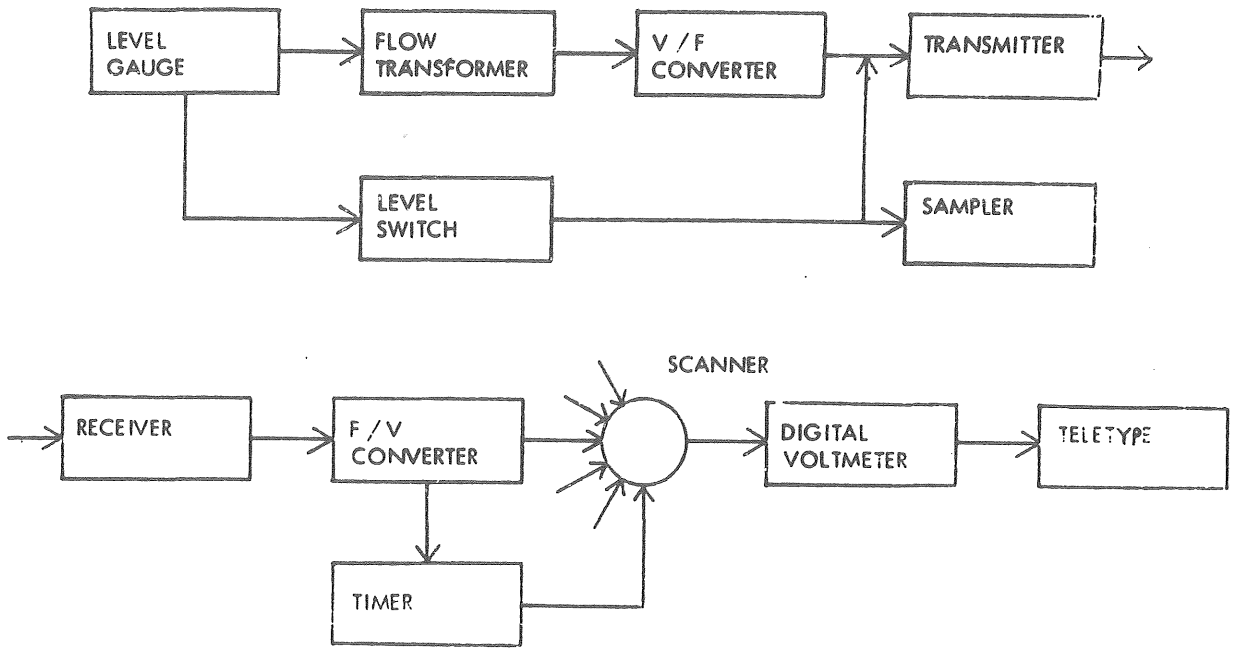

Fig. 2. Data transmitting system.

In Linköping the water level is registered by an analog recorder on diagram paper at a speed of 60 mm/hour. Also in Gothenburg the registration equipment has been redoubled by installing analog recorders in each area. For time synchronization time check marks are made on every service occasion. At present an investigation is being made of the possibilities of installing quartz crystal timers in both rain and flow-measuring recorders.

C. Instrumentation for storm water sampling.

In the areas 1-7, see the above, composite samples are taken flow-proportionally by automatic samplers directed by the flow gauges. An outline of a sampler can be seen in fig. 3. In the areas 1 and 2 up to 30 discrete samples can also be taken per runoff event with arbitrary time settings (see fig. 4). In the areas 8-10, sampling is carried out manually.

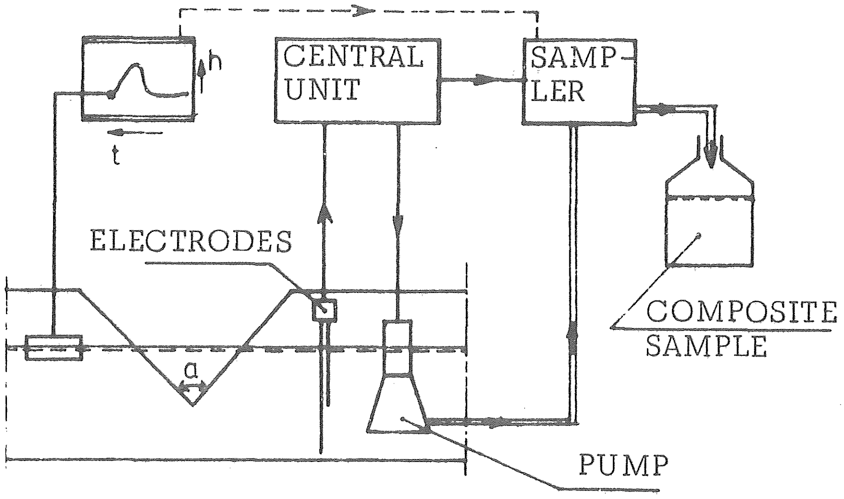

Fig. 3. Storm water sampler for taking composite flowproportional samples.

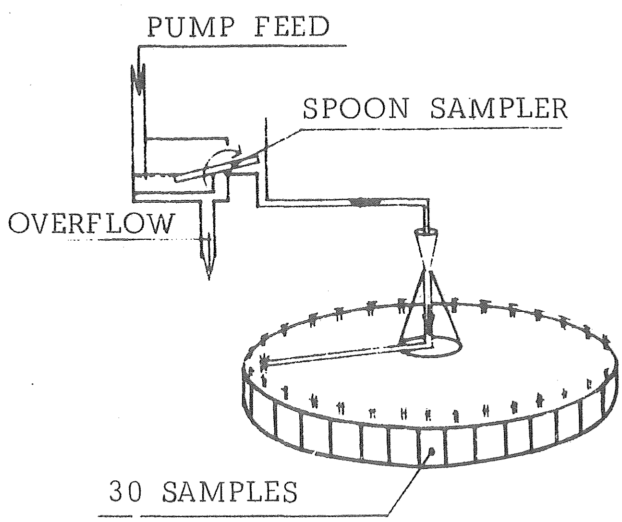

Fig. 4. Storm water interval sampler.

D. Instrumentation for the investigation of pollutant sources.

The pollutant sources are investigated in the areas 1-4.

Total atmospheric fallout is sampled by five open standardized deposit gauges in each area. Sampling period: one month.

Precipitation is sampled by special gauges which automatically open at the start of rainfall and close after the end of rainfall. Samples are taken simultaneously with the runoff sampling.

Ambient air is sampled at two-day periods by automatic suction samplers, one for particles and one for gases.

Corrosion rates are measured partly by a standardized loss-of-weight method, partly by means of an electrolytic cell where the integrated current is proportional to the corrosion rate. The exposure time for the corrosion plates is one month. Continuous plates are also exposed. The electrolytic cells are continuous.
Corrosion products are measured by analysing rain water running from special plates. This is partly done after an exposure time of one month and partly for the same rainfalls for which the storm water runoffs are sampled.

E. Supporting investigations.

In addition to the above described measurements the following supporting investigations have been carried out:

1. Catchments with storm water infiltration facilities have been equipped for studies of the groundwater level and the piezometric head.
2. Measurements of runoff from some small areas in the Bergsjön basin are carried out.
3. In the Torslanda research basin measurements of sewage and drinking water flow and groundwater levels are carried out as well as of storm water runoff.
4. All areas are mapped in detail with regard to surface materials, slopes, geology, subbasins, construction materials and data about the sewer systems.
5. Traffic intensity is also investigated.

Accuracy and Reliability of Rainfall and Runoff Measurement

The rain measurement is influenced by topography, surrounding objects, influence of wind and instrumentation defects and so on. There will also be some errors during the data processing. The total error in rain intensity is estimated to be about ± 15 %. Runoff measurement accuracy depends on the accuracy of the stage-discharge curve and the accuracy of the water stage instrument. We estimate the total error to be about ± 10 % when registration is on a strip chart.

The rain instruments have been functioning well during about 90 % of the time and the runoff measurement during about 95 %. The telemetered system has caused us some problems, especially the electronic linearisation units. The reliability of this system is about 95 %.

Data Analysis

Processing of field data.

Occurances of rain and flow intensities are punched on paper tapes by means of a so-called digitizer together with the time check marks. The data are then processed by computer and errors are corrected, whereafter the information is stored on magnetic tape. The punched paper tape of the telemetered data is also processed by computer and stored on magnetic tape.

Rainfall-runoff analysis.

The stored data are used for model analysis and to evaluate several interesting parameters concerning storm water volumes, flow-rates and quality. Below you will find some examples of the analysis. For Bergsjön catchment rainfall-runoff events have been analysed. As for rainfall data four criteria have been used to classify a rainfall event (see fig. 5).

a/ Rain intensity $\geq$ 0.1 mm/hour.

b/ Rain intensity $<$ 0.1 mm/hour is allowed during intervals of a maximum 15 minutes within the rain.

c/ Total rain duration $\geq$ 2 minutes.

d/ Total rain volume $\geq$ 0.1 mm.

The runoff belonging to a rainfall is defined as the runoff between the start if rain and 30 minutes after the end of rainfall. The baseflow is the linearly interpolated runoff between these points. Fig. 6 shows a regression analysis between rain volumes and baseflow separated runoff volumes.

The initial loss (depression storage) was found to be 0.3 -0.5 mm. The runoff coefficient defined by the rational method was studied (see fig. 7), and it was found that it is very important to chose the right duration of rainfall coupled with the time of concentration. Moreover, the time varies with the runoff rate (fig 8).

Field data are also used to test different mathematical models. A detailed mathematical model has been tested (see Arnell & Lyngfelt, 1976). It divides the runoff process into five submodels; infiltration, surface depression, overland flow, gutter flow and sewer routing.

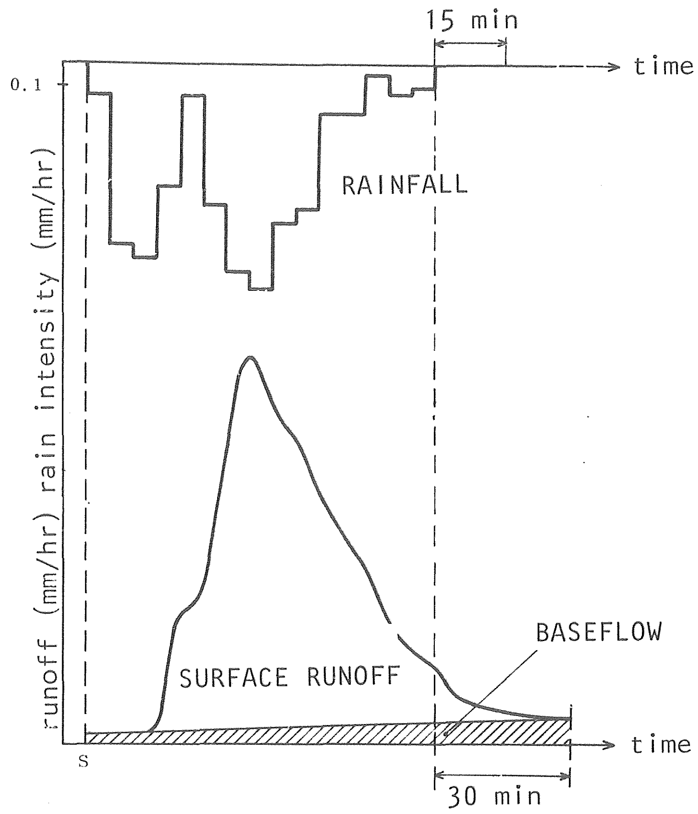

Fig. 5. Rainfall event with definitions of runoff and baseflow.

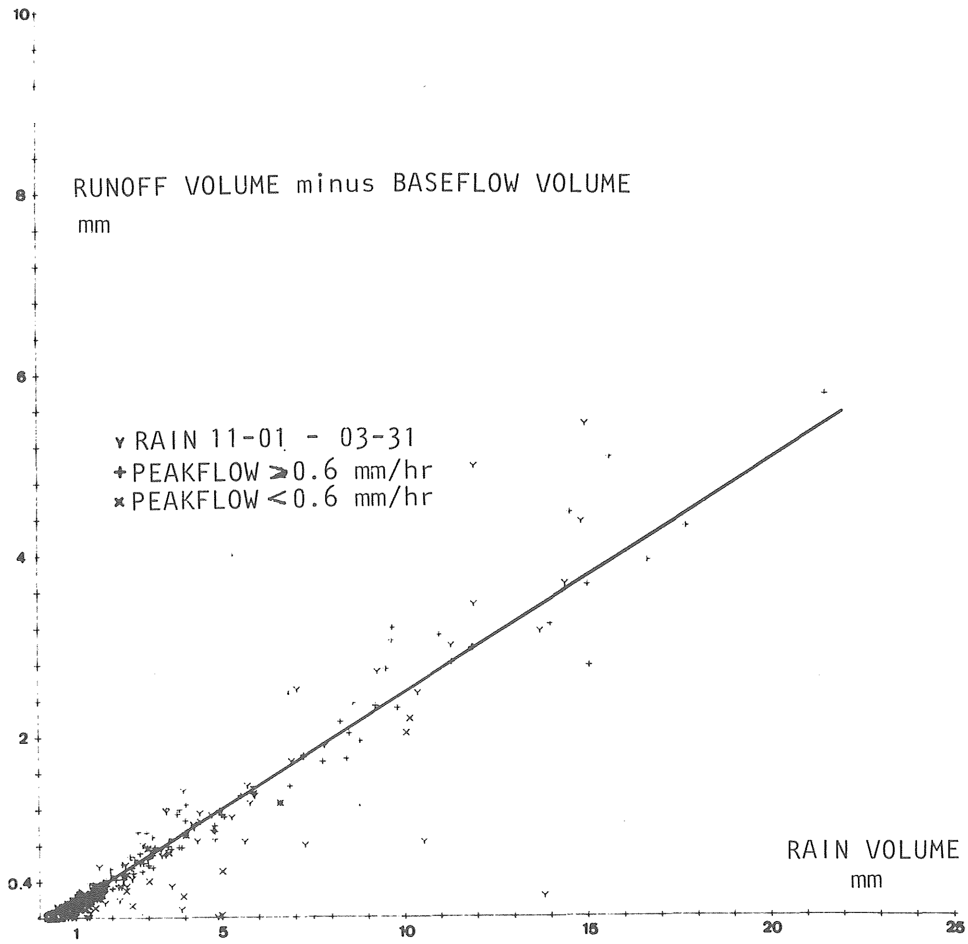

Fig. 6. Regression analysis of rainfall volume and baseflow-separated runoff volume.

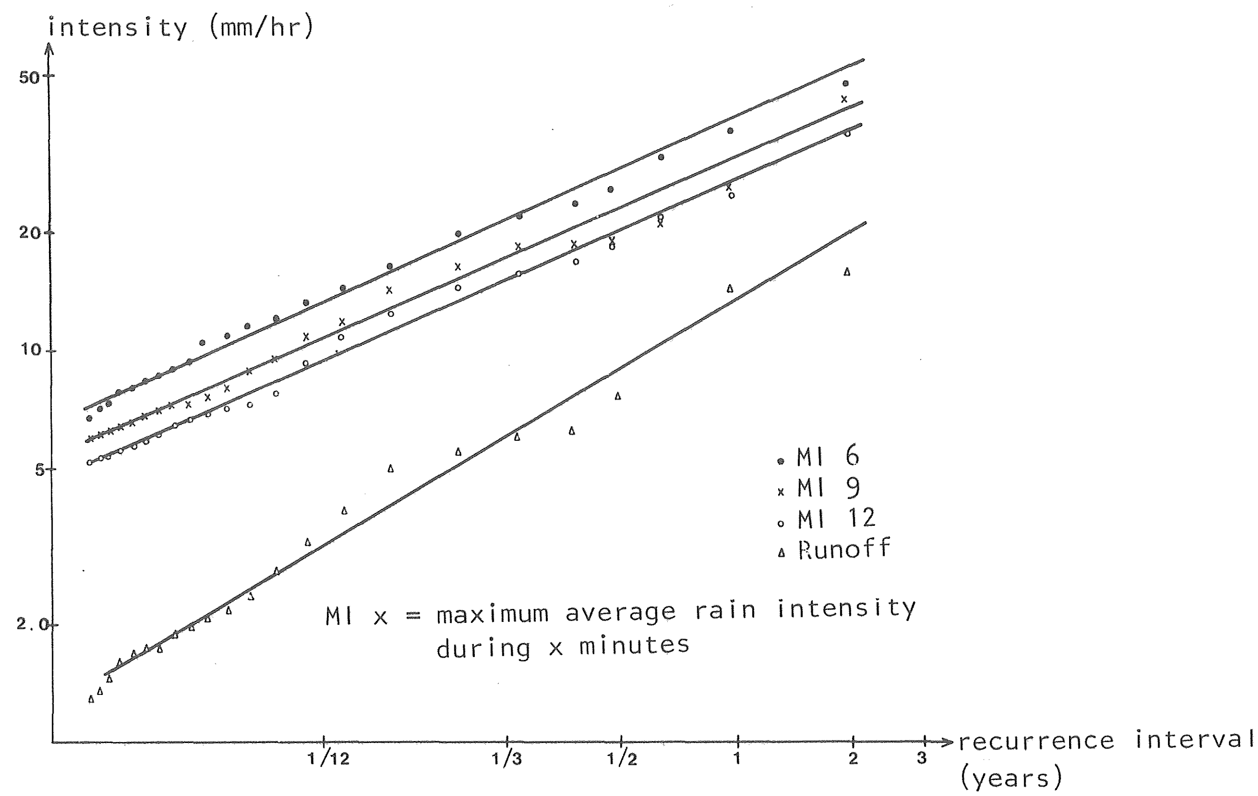

Fig. 7. Distribution functions for maximum rain intensity of different durations and peak flows in the Bergsjön area 1973 - 1974.

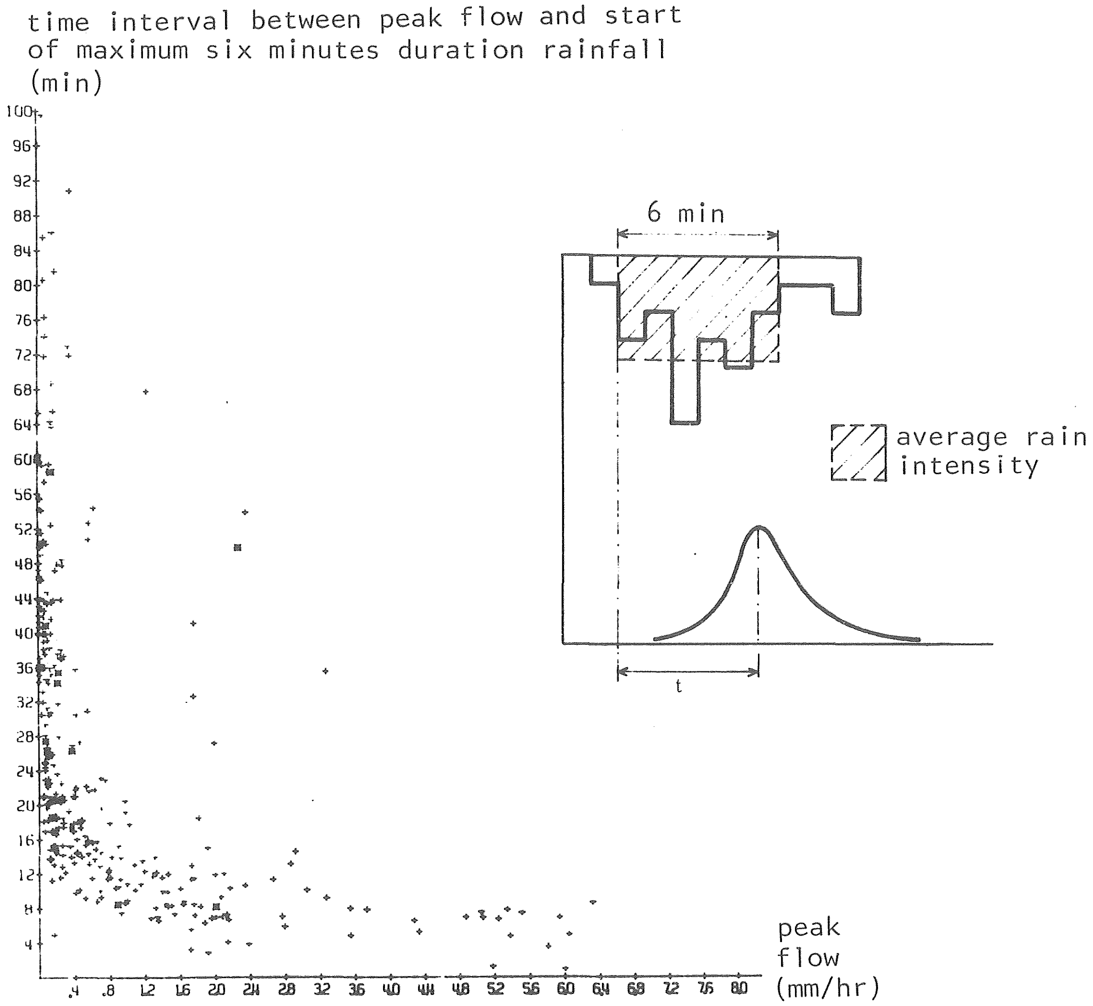

Fig. 8. Time interval between peak flow and start of maximum six minute duration rainfall plotted against peak flows.

The overland flow submodel is based on kinematic wave theory and the sewer routing is solved according to the RRL-method (diffusive kinematic wave). The model has up to now been tested in the Bergsjön area with relatively good results (fig 9). The next step planned is to apply the model in the rest of the research areas and to test different degrees of subdivision of the runoff areas. Sensitivity analysis of parameters together with evaluation of the parameters of rainfall-runoff measurements will be carried out.

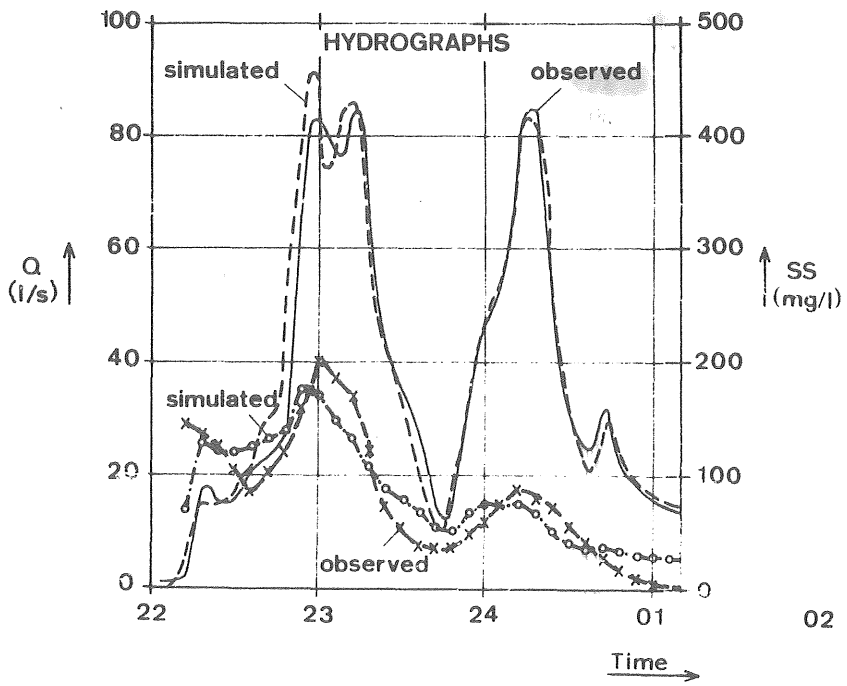

Fig. 9. Simulation of storm water runoff, quantity and quality, for the Bergsjön runoff area.

Using a 30-year record of storm events in Gothenburg, the approach of using a set of real rain events for the design of different parts of storm sewer systems is being tested.

Storm water quality analyses.

The storm water samples are analyses in a laboratory for among other things total solids, volatile total solids, suspended solids, volatile suspended solids, COD, total phosphorus, sulphate, chloride, pH, iron, zink, copper, lead and bacteria. In a special project 17 different heavy metals and chlorinated hydrocarbons as well as other organic substances, as poly aromatic hydrocarbons are being studied. The laboratory results are fed into a computer together with the funoff data for statistical evaluations (fig 10-12). A mathematical quality model has to some extent also been tested on data from the Bergsjön area (fig 9), (Svensson, 1976). Studies to develop a more accurate mathematical model for the storm water quality are going on.

Studies of storm water pollutant sources.

The pollutant sources basically studied are atmospheric fallout, precipitation and corrosion of construction material. The ambient air quality is studied in order to determine the corrosion climate. The mass flows from all the pollutant souces, including random ones like traffic and human activities, will summarize the pollutant mass flow in the storm water. However, a mathematical model has to be used, partly because of the complexity of the data and partly because of the continuity of the process. Such a model is being developed. A pilot study has shown the possibility of predicting the storm water quality by means of the pollutant sources. The pilot study also indicated the importance of the corrosion of construction material to the storm water quality.

Studies of water balance.

In the Torslanda area (western Gothenburg), drinking water, waste water and storm water are simultaneously measured at three points (quantity and quality). The ground water movements are investigated. Mass balances for water and pollutants will be set up and analysed by computer. At least the American model STORM and the Norwegian model NIVA (Lindholm, 1974) will be tested on the data from Torslanda. At these runs alternatives to the water management in the area will be investigated and propositions for future expansion of the area and proper water handling will be made. The measurements are backed up by thorough investigations of the conditions and performances of the water and sewage nets. The analyses will be made during 1977.

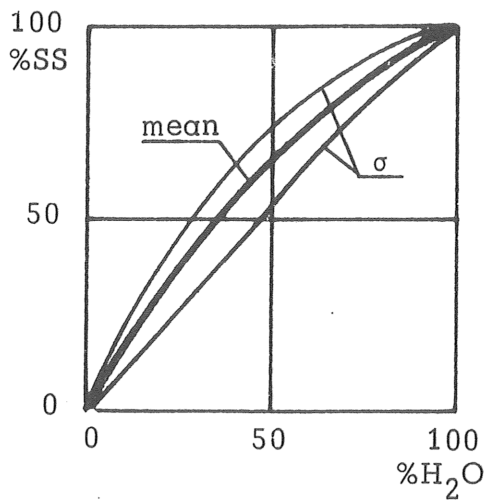

Fig. 10. Accumulated suspended solids related to accumulated water volume during the runoff. Mean values of 33 events in the Bergsjön area.

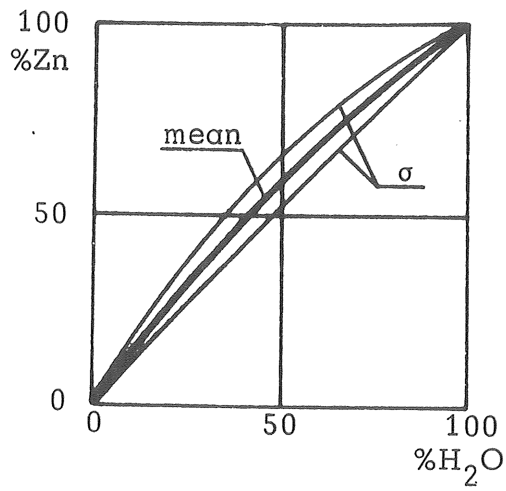

Fig. 11. Accumulated amount of zink related to accumulated water volume during the runoff. Mean values of 23 events in the Bergsjön area.

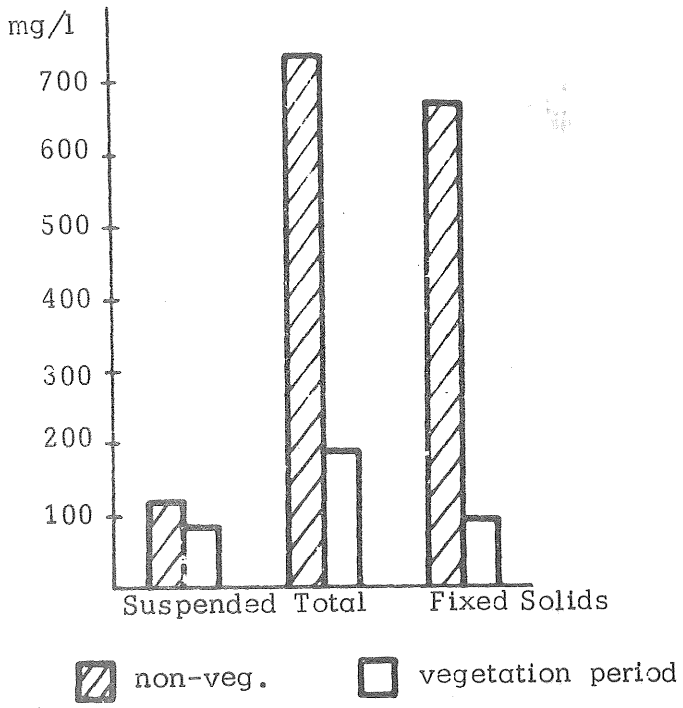

Fig. 12. Mean solids concentrations during vegetation and non-vegetation periods in the Bergsjön area, showing the influence of de-icing by salting.

Storm water infiltration studies.

The purpose of this project is to analyse the possibilites of local infiltration of storm water and to examine if the dimensions of storm water pipes can be reduced (Cederwall & Holmstrand, 1976). The aim is also to study the effects on gruondwater and soil water. The total water balance including ground water and soil water will be measured. Separated rainfall events will be evaluated for a few percolation basins. The previously mentioned runoff model will be used to simulate retention and runoff through the infiltration storages.

DATA COLLECTION SYSTEM AT THE KLOSTERGÅRDEN CATCHMENT AREA IN LUND.

Background

As a complement to the rural basin Värpinge, which has been studied for 6 years, an urban catchment Klostergården in the southwestern part of Lund was chosen for study. The purpose of this investigation is to compare the parameters of the respective water balances for the rural and urban cathments and to study the urban runoff process. The Klostergården catchment is dominated by six to eight story dwellings. The catchment area is 13.9-ha, out of which 48 % consists of impermeable surfaces such as roads, parking-lots and roofs. Field measurements were started in June 1976.

Rainfall Measurements

For the recording of rainfall intensity, an instrument which operates on the "tipping-bucket" principle has been constructed. In order to assure good measurement, the instrument has been equipped with a 3000 cm^2 catchment surface. The volume of water resulting in a tipping is dependent on the rainfall. Thus a conversion from the recorded number of tippings to intensity must be made via a calibration curve. On the average for the three gauges involved, each tipping is equal to 0.02 mm of rain.

Runoff Measurements

Runoff is measured at the outlet of the basin and at four small impermeable subareas within the basin. The principle of the gauge is shown in fig 13. A vertical pipe filled with an electrolyte (0.5 % NaCl) is connected to the water in an inlet, and for the catchment gauge is connected to the storm drain through a rubber menbrane. Two parallell platinum wires are mounted in the vertical pipe. By measuring the electrical conductivity of the wires in the electrolyte the water level can be obtained. Because the pipes are placed upstream from V-notch weirs the runoff is determined by a rating curve. To increase the reliability of the system a supplemental mechanical recorder has been installed at the catchment outlet.

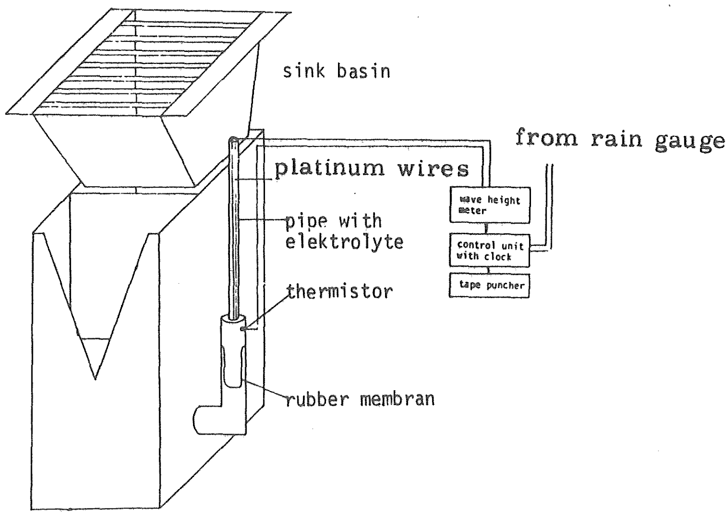

Fig. 13. Apparatus for runoff measurements in a gutter inlet.

Central Recording

In order to transfer signals from the measuring units to a tape puncher, a special control unit has been developed. This unit consists of a clock, a digital voltmeter and a pulse counter. The recording (tape punching) starts automatically when an initial pulse from a rain-gauge triggers the control unit. The time interval between each punching is set at one minute. That is each minute the voltage of the runoff gauges and the number of tippings for each rain-gauge are punched. Termination of recording is determined by the elapsed time since the last pulse from any rain-gauge was received, the limit being one hour. Since all the instruments are connected to the same clock, there is an absolute synchronization of recording time for rainfall and runoff (fig 14).

The central unit where recording takes place is situated in the cellar of a building within the catchment. All cables connected to the gauges are placed in the storm drains.

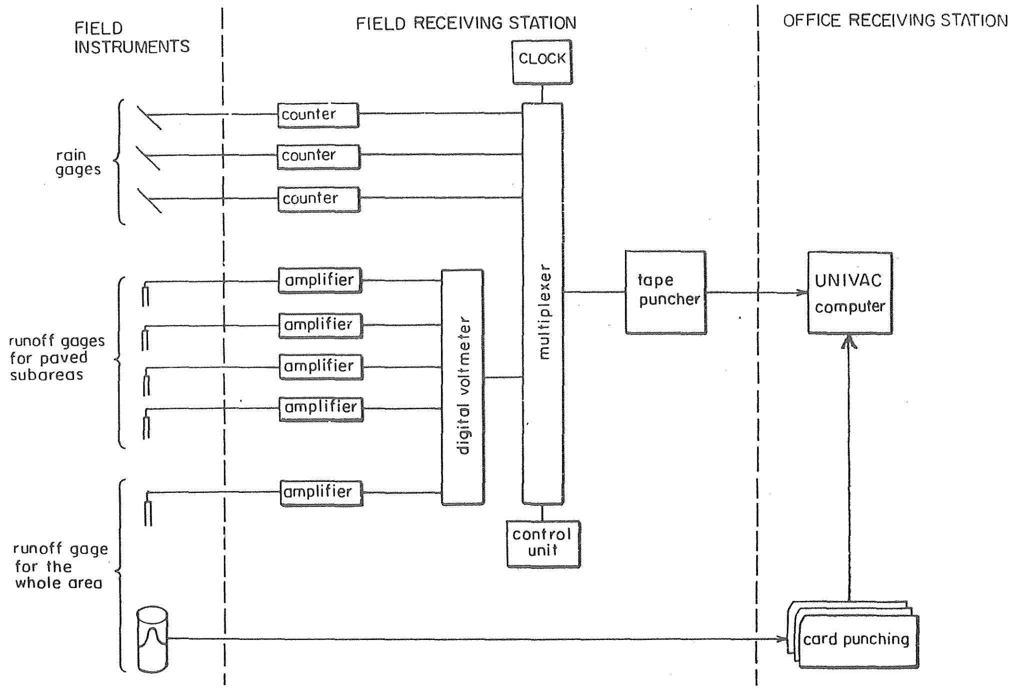

Fig. 14. Klostergården data collection system.

Water Sampling

During the first months of recording, water samples have been taken during one storm.

Data Analysis

As an example of the simultaneous recordings of precipitation and runoff from an impermeable parking-lot, with an area of 291 m^2, are shown in fig 15. The figure also shows a calculated hydrograph by means of a non-linear model

$Q = A \cdot S^B$ where A and B are constants, S storage and Q runoff.

The constants were determined from 30 other storm events. (Falk & Niemczynowics, 1976).

For the rural basin of Värpinge the water budget is calculated on a monthly basis as the soil moisture contents and the groundwater level are recorded. The same calculations will be carried out for the Klostergården area.

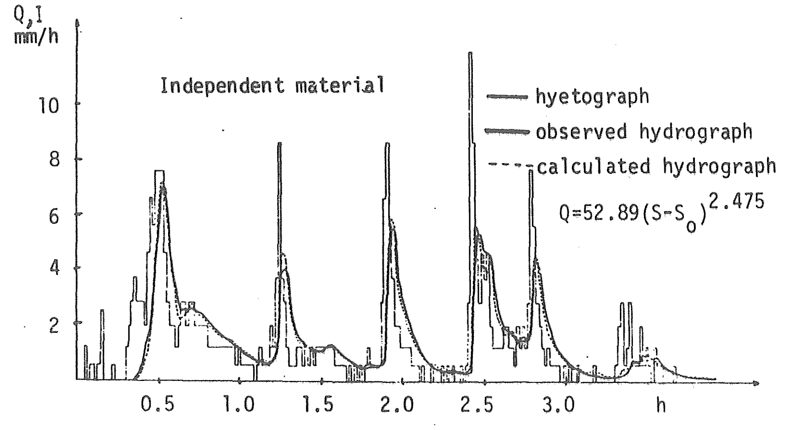

Fig. 15. Rainfall 75-08-18. Observed hyetograph and hydrograph. Calculated hydrograph with non-linear model. Independent material.

WATER BUDGET FOR URBAN AREAS

Background

Recently completed is a report, under the direction the Swedish Council for Building Research (BFR), Chalmers University of Technology (CTH) and the Lund Institute of Technology (LTH) (Carlsson & Falk, 1976). The aim of this was to:

- shortly describe the drawbacks in the management of water in urban areas and state the costs to the community.
- specify a research program for the continued urban-hydrological research both for the present and the future.

A few parts of the report are given below.

Quantitative Water Balance in Urban Areas

Water budget models can be formulated with respect to both an outer system (the "natural" cycle encompassing urban areas) and an inner system (the conveyance and distribution of water for uses within urban areas).

Discussed here first is an outer system water balance for urban areas in Sweden from the perspective of national annual totals. The total national urbanized area is 4024 km^2 (as of 1970), having an estimated average annual precipitation of 700 mm. Evapotranspiration is estimated at 450 mm per year from permeable surfaces and evaporation is ignored for impermeable surfaces. Of the groundwater leaking into sewer systems, one-third is assumed to enter storm water systems and the other two-thirds the waste water systems. Also assumed is that no surface runoff is generated from permeable areas and that precipitation falling on them enters the ground and is mostly conveyed via sewer and eventually reaches receiving water bodies. Paved and other impervious surfaces are taken as 30 % of the total urbanized area. The resulting general urban area water budget for Sweden is shown in fig 16, the right part, covering the outer system of "natural" cycle. The volumes indicated (in millions of cubic meters per year) should be regarded as rough approximations.

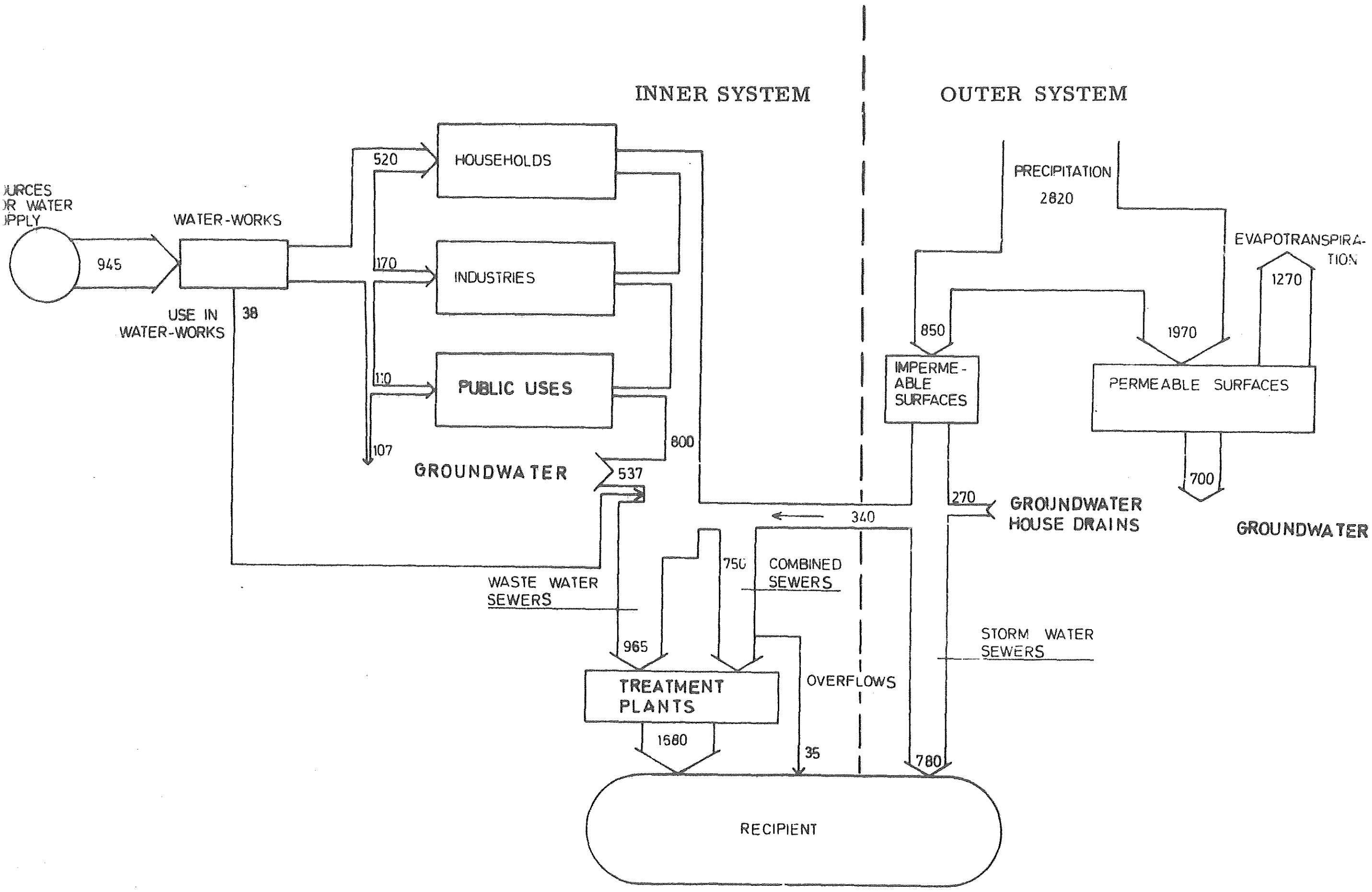

Fig. 16. General urban area water budget for Sweden, inner and outer systems (after Carlsson & Falk, 1976).

Based on data from the Swedish Water and Sewerage Association, a general urban area water budget for Sweden has also been estimated for the inner system, for the conveyance and distribution of water for uses within urban areas, shown in fig 16, the left part. Of the total length of storm water and combined sewers, it has been estimated that 30 % is combined, partly based on the assumption that about 2 % of the average annual waste water volume circumvents treatment at sewage purification plants via combined sewer overflows entering receiving waters.

The total urban water budget can be described as the sum of the outer and inner systems, where the sole connections could be "via combined sewers" (340 x 10^6 m^3/year) and "receiving waters".

Pollution Load due to Urbanization

The theoretical pollution load of effluents from local waste water treatment plants in urban areas (including connected small industries) imposed on the water courses and coastal waters of the country in January 1975 amounted to 33000 tons of BOD_7 per annum, 3000 tons phosphorus per annum and 17000 tons of nitrogen per annum. These estimates are based on characteristic amounts of pollution of 70 g of BOD_7, 3.2 g of phosphorus and 11 g of nitrogen per person per day: and the theoretical purification capacity of treatment plants with regard to each of these constituents.

Using average values of 80 g of BOD_7/m^3, 3 g of P/m^3 and 10 g of N/m^3 multiplied by the total combined sewer overflow volume of 35×10^6 m^3 in fig 16, the following values of pollution load are obtained: 2800 tons of BOD_7/year, 105 tons of P/year and 350 tons of N/year. Corresponding rough estimates for storm water pollution, assuming an average pollution content of 15 g of BOD_7/m^3, 0.1 g of P/m^3 and 1.5 g of N/m^3 applied to a total water volume of 840×10^6 m^3 per annum are: 12600 tons of BOD_7 per annum, 84 tons of phosphorus per annum, and 1260 tons of nitrogen per annum. Using similar assumptions, the pollution load from suspended solids and zink have been estimated.

The preceding pollution load estimates should not be regarded as highly reliable because of uncertainty on all components, particularly for combined sewer overflows and storm water discharges. Regardless, these estimates do give indication of the relative magnitude of loadings. In summary, the estimated total pollution loads on the receiving waters of Sweden, in tons per annum, are:

Pollutant	Waste water	Combined Sewer Overflows	Storm Water Discharges	Sums
SS	25200	10500	117000	152700
BOD_7	33000	3000	12000	48000
P	3000	100	100	3200
N	17000	400	1200	18600
Zn	170	10	130	310

REFERENCES

Arnell V & Lyngfelt S, 1976: "Some Results from Runoff Studies in Bergsjön, Göteborg" -Paper presented at the Nordic Hydrological Conference 1976, Reykjavik.

Carlsson L & Falk J, 1976: "Urban Hydrology, Review of Research Needs" (to be published in English). -Department of Water Supply and Sewerage, Chalmers University of Technology, Publication B 76:6, Gothenburg. (Department of Water Resources Engineering, University of Lund, Bulletion serie A no 56, Lund).

Cederwall K & Holmstrand O 1976: "Local Infiltration of Storm Water" - Paper presented at the Nordic Hydrological Conference 1976, Reykjavik.

Falk J & Niemczynowics J 1976: "Runoff from impermeable surfaces", "Tenth Anniversary Papers on Research in Progress" - Department of Water Resources Engineering, Lund Institute of Technology/University of Lund, Bulletin serie A, No 55, Lund.

Lindh G 1976: "Urban Hydrological Modeling and Catchment Research in Sweden" - ASCE Urban Water Resources Research Program, Technical Memorandum No IHP-7, New York.

Lindholm O G 1974: "A Pollutional Analysis of the Combined Sewer System" - Division of Hydraulic, The University of Trondheim, The Norwegian Institute of Technology, Trondheim.

Malmquist P-A & Svensson G 1975: "Urban Storm Water Quality" (in Swedish with summary in English). - Department of Water Supply and Sewerage, Chalmers University of Technology, Publication B 75:3, Gothenburg.

Nilsson L-Y 1973: "Verka representative basin" - Department of Land Improvement and Drainage, School of Surveying, Royal Institute of Technology, Report 3:1, b-e, Stockholm.

Sjöberg A 1976: "Calculations of Unsteady Flows in Regulated Rivers and Storm Sewer Systems" (in Swedish with summary in English). - Department of Hydraulics, Chalmers University of Technology, Publication No 87, Gothenburg.

Svensson G 1976: "Some Aspects of Urban Runoff Quality Modeling" - Paper presented at the Nordic Hydrological Conference 1976, Reykjavik.

CHALMERS UNIVERSITY OF TECHNOLOGY

URBAN GEOHYDROLOGY RESEARCH GROUP

Departments of:
Geology
Geotechnical Engineering
Hydraulics
Water Supply and Sewerage

Reports:

No 1 The effect of urbanization on surface water runoff and ground water recharge. Interim reports (1972-07-01 - 1973-03-01). 1973. (In Swedish).

No 2 Leif Carlsson: Ground water lowering Part 1. Evaluation of the hydraulic properties of aquifers using pumping test data. 1973. (In Swedish).

No 3 Leif Carlsson: Ground water lowering Part 2. Evaluation of the hydraulic diffusivity of confining beds using pumping test data. 1973. (In Swedish).

No 4 Viktor Arnell: Precipitation instruments. A review of some instruments. 1973. (In Swedish).

No 5 Viktor Arnell: Intensity - Duration frequency relationships for heavy rainfalls in Göteborg during the 45-year period 1926 - 1971. 1974. (In Swedish).

No 6 The effect of urbanization on surface water runoff and ground water recharge. Interim reports (1973-03-01 - 1974-02-01). Göteborg 1974. (In Swedish).

No 7 Olov Holmstrand, Per O Wedel: Engineering geological maps - Literature research. 1974. (In Swedish).

No 8 Anders Sjöberg: Interim Report. Models for Gradually Varied Unsteady Free Surface Flow. Development and Discussion of Basic Equations. Preliminary Studies of Methods for Flood Routing in Storm Drains. 1974.

No 9 Olov Holmstrand (ed.): Seminar on Engineering geological maps. 1974. (In Swedish).

No 10 Viktor Arnell, Börje Sjölander: Measurement of rain intensity in Göteborg. Description of measuring network. 1974. (In Swedish).

No 11 Per-Arne Malmquist, Gilbert Svensson: The character and properties of urban storm water.Results from investigations in Stockholm and Gothenburg 1969-72. 1974. (In Swedish with an English summary).

No 12 Viktor Arnell, Sven Lyngfelt: Interim Report. Rainfall - runoff model for simulation of storm water runoff in urban areas. 1975. (In Swedish).

No 13 Viktor Arnell, Sven Lyngfelt: Rainfall - runoff measurements at Bergsjön, Göteborg 1973 - 1974. 1975. (In Swedish).

No 14 Per-Arne Malmquist, Gilbert Svensson: Urban Storm water quality. Interim report from a study in Gothenburg. 1975. (In Swedish with an English summary).

No 15 Viktor Arnell, Sven Lyngfelt, Anders Sjöberg, and Gilbert Svensson: Storm water. Papers presented at the conference on urban hydrology at Sarpsborg, Norway, 1975. 1976. (In Swedish with English summaries).

No 16 Leif Andréasson, Leif Carlsson, Klas Cederwall, Bengt-Arne Torstensson, and Per Wedel: Ground water. Papers presented at the conference on urban hydrology at Sarpsborg, Norway, 1975. 1976. (In Swedish with English summaries)

No 17 Olov Holmstrand: Soil water investigations in an urban area. 1976. (In Swedish).