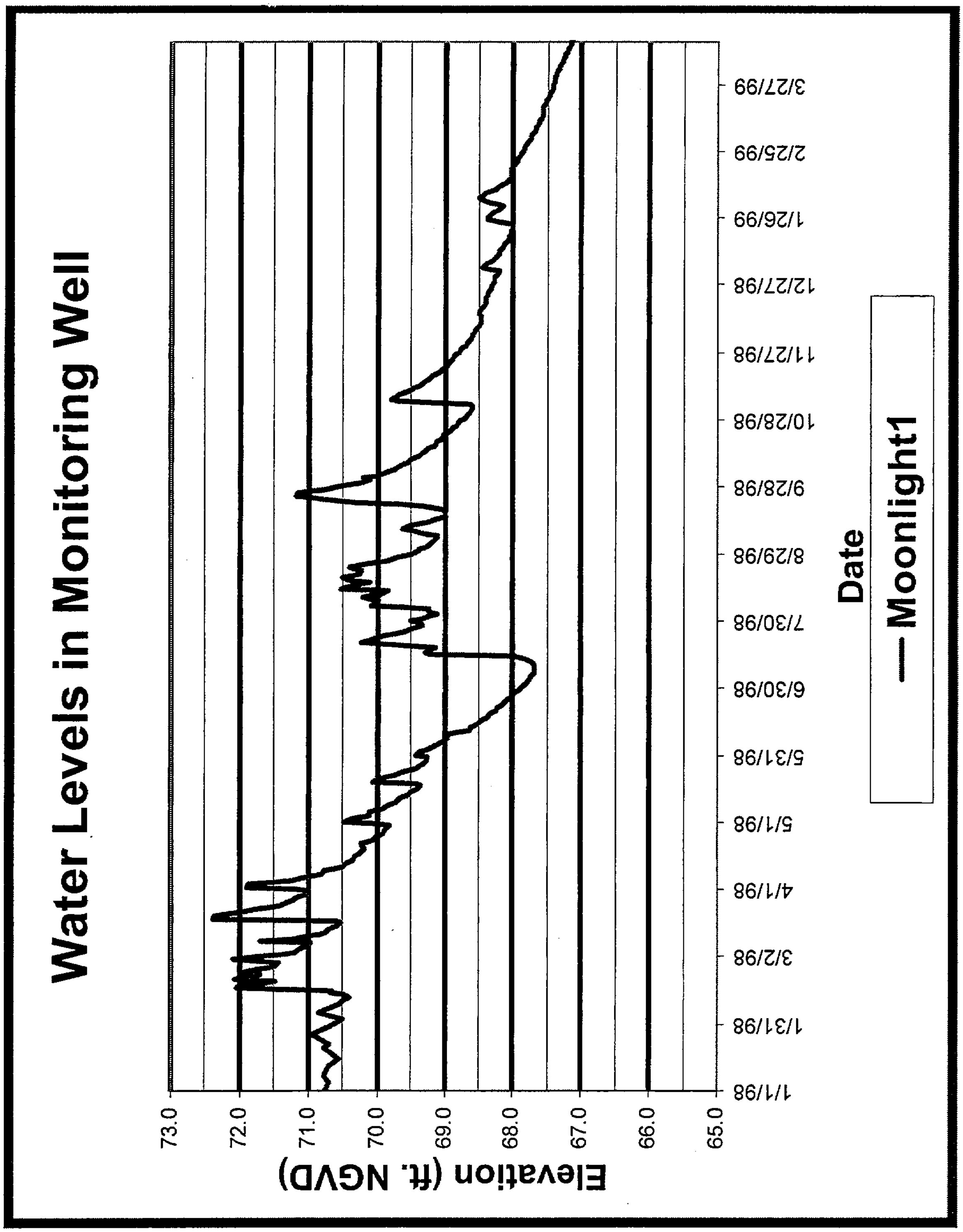
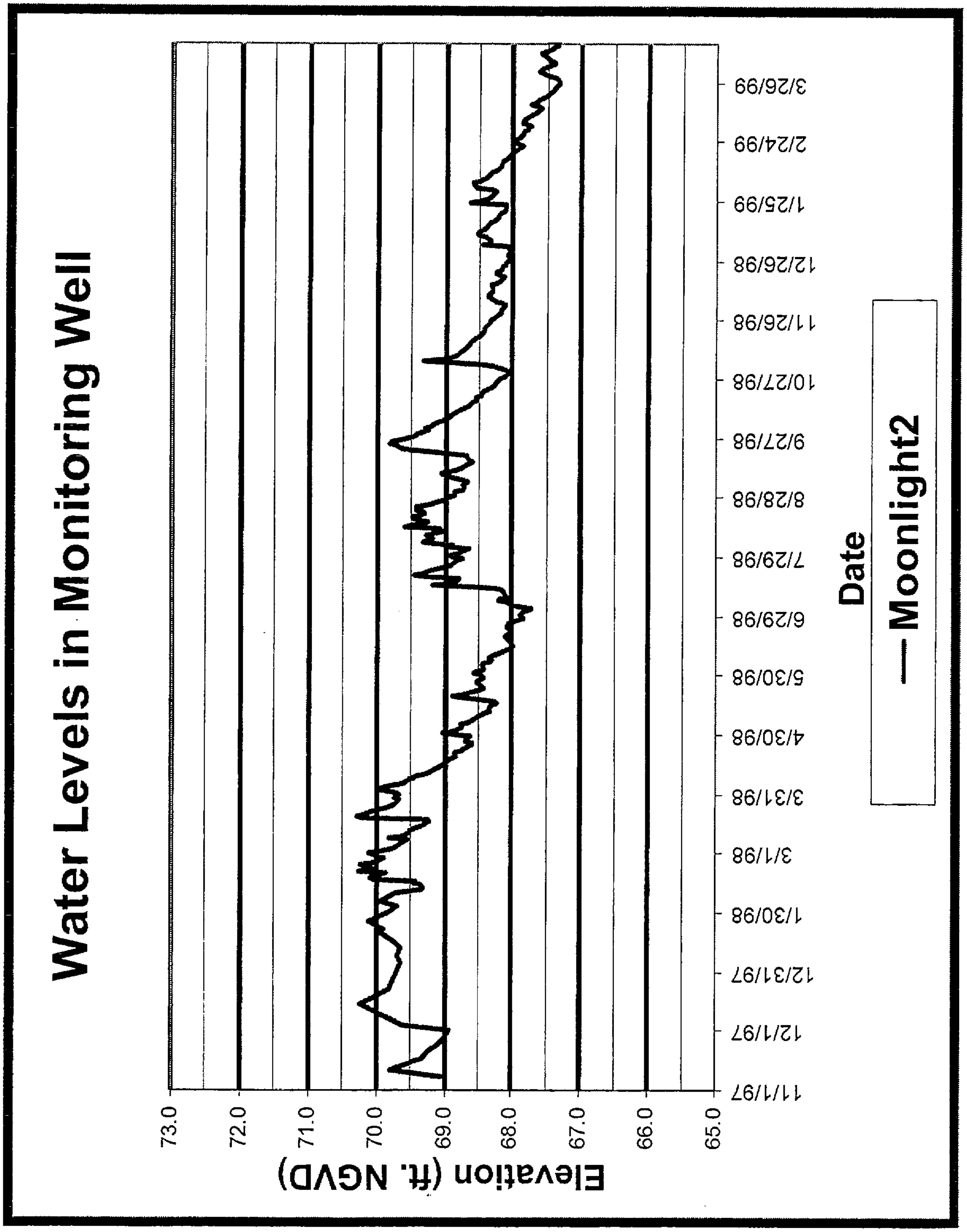


Water Levels in Monitoring Well
Elevation (ft. NGVD)
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
1/1/98
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
10/28/98
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
— Moonlight1


Water Levels in Monitoring Well
Elevation (ft. NGVD)
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
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11/1/97
12/1/97
12/31/97
1/30/98
3/1/98
3/31/98
4/30/98
5/30/98
6/29/98
7/29/98
8/28/98
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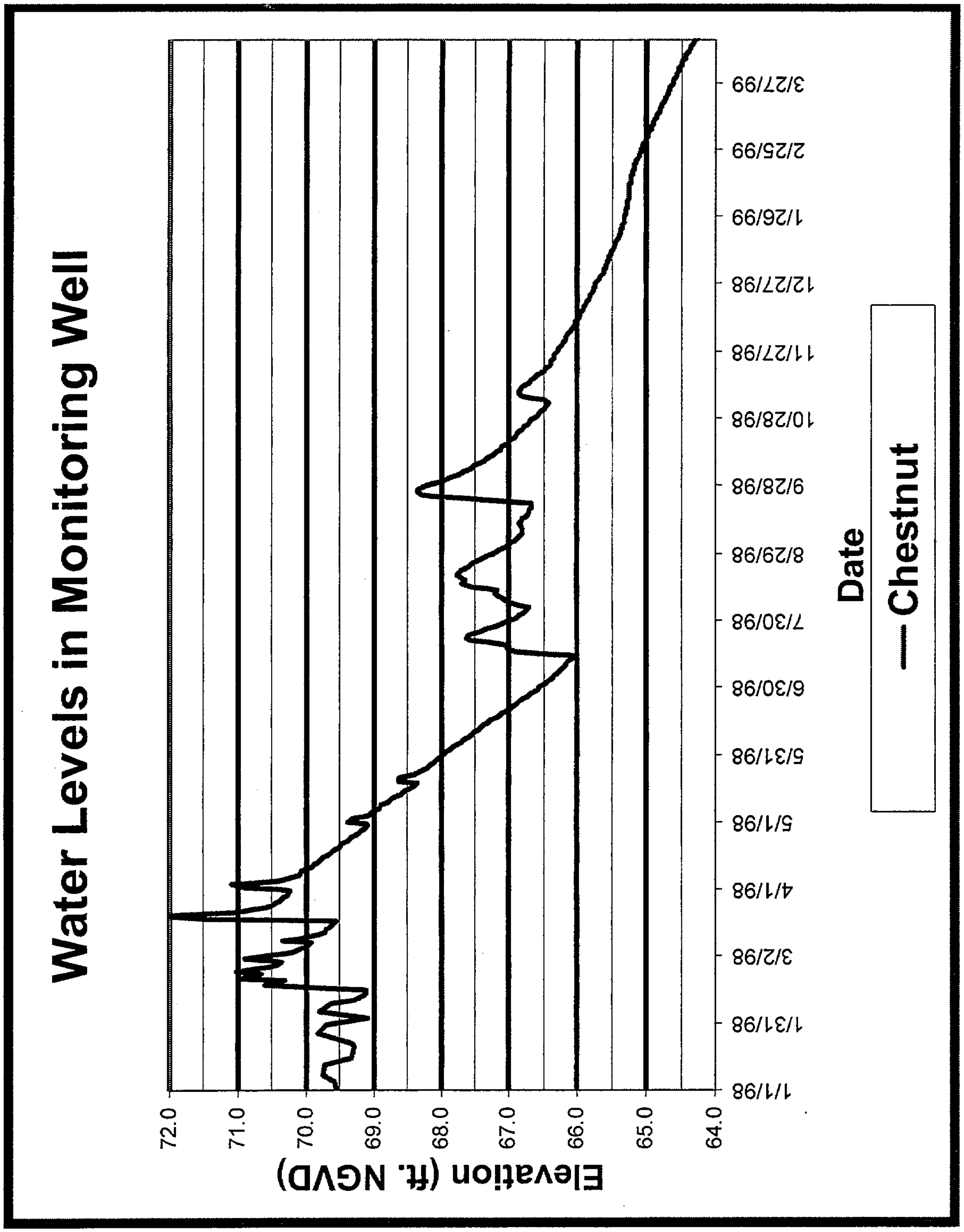
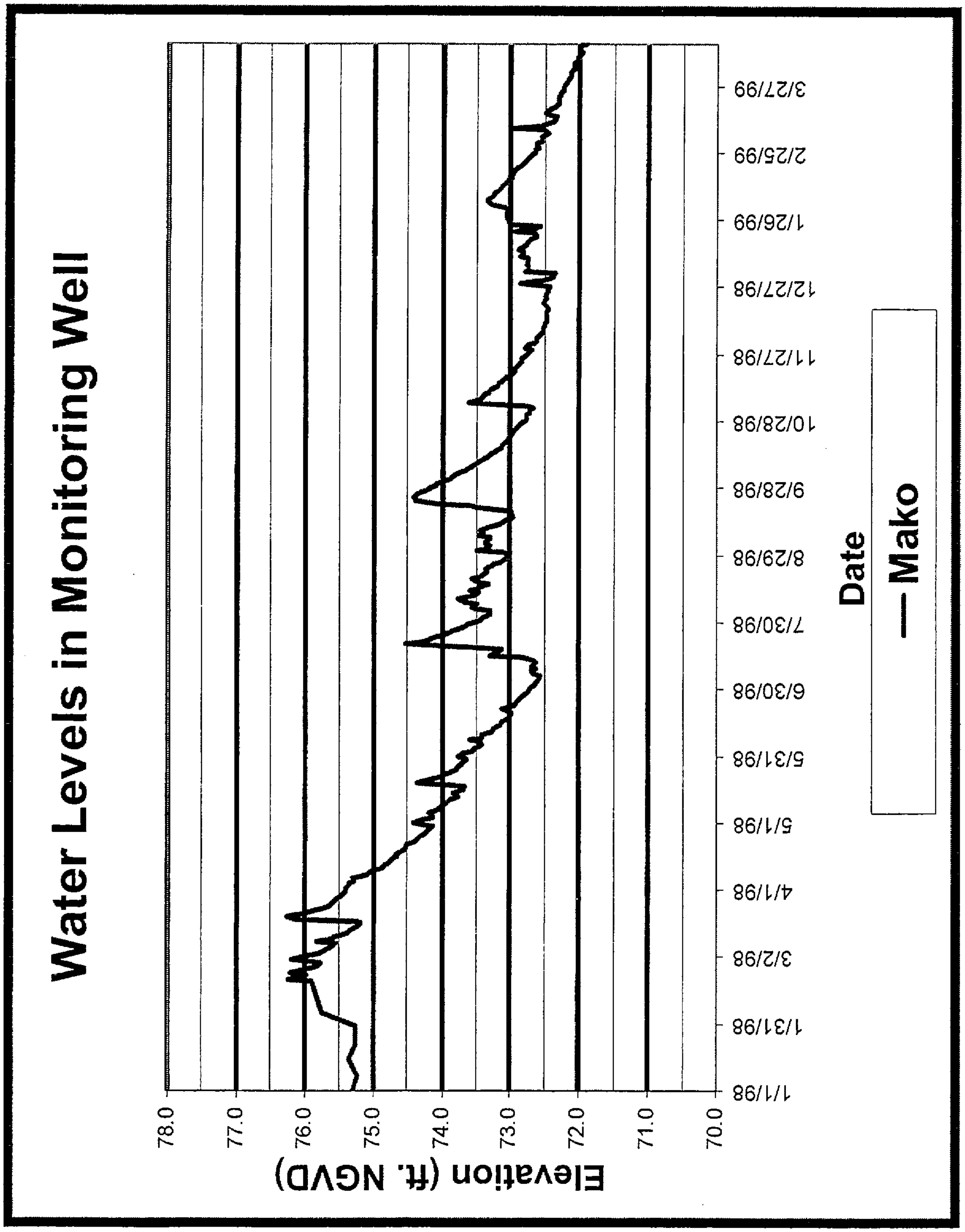
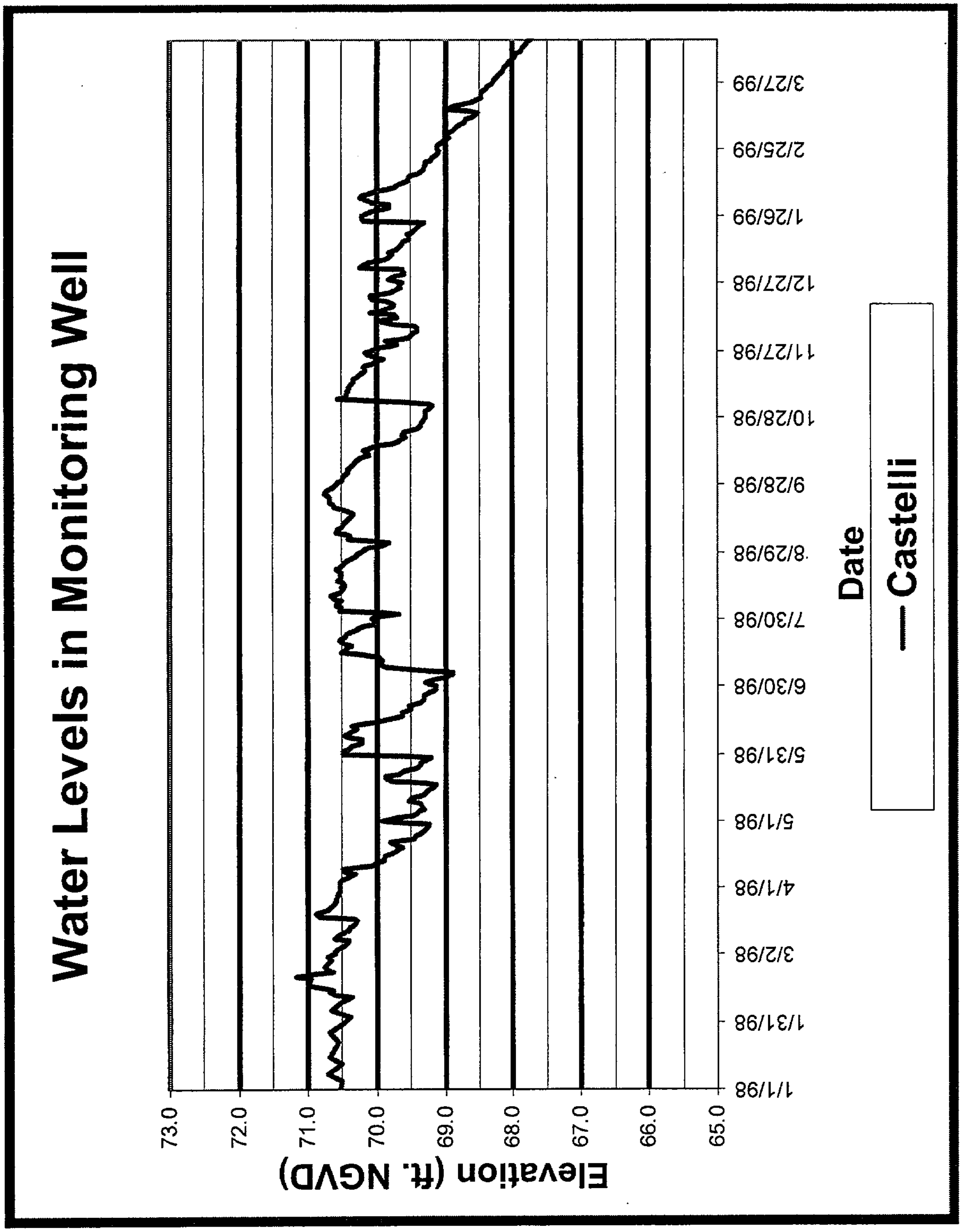
11/26/98
12/26/98
1/25/99
2/24/99
3/26/99
Date
Moonlight2



Water Levels in Monitoring Well
Elevation (ft. NGVD)
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
64.0
1/1/98
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
10/28/98
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
— Chestnut


Water Levels in Monitoring Well
Elevation (ft. NGVD)
78.0
77.0
76.0
75.0
74.0
73.0
72.0
71.0
70.0
1/1/98
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
10/28/98
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
— Mako


Water Levels in Monitoring Well
Elevation (ft. NGVD)
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
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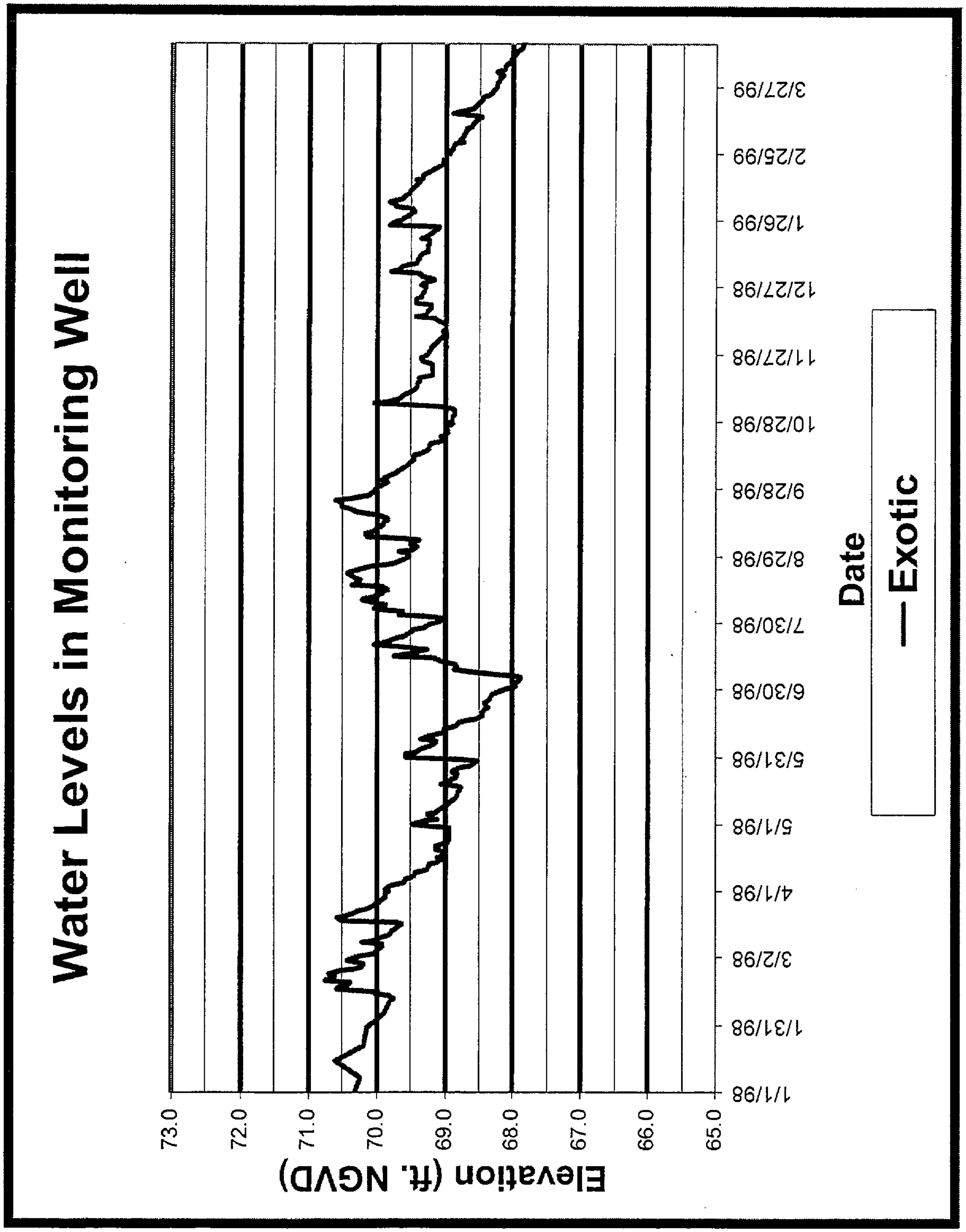
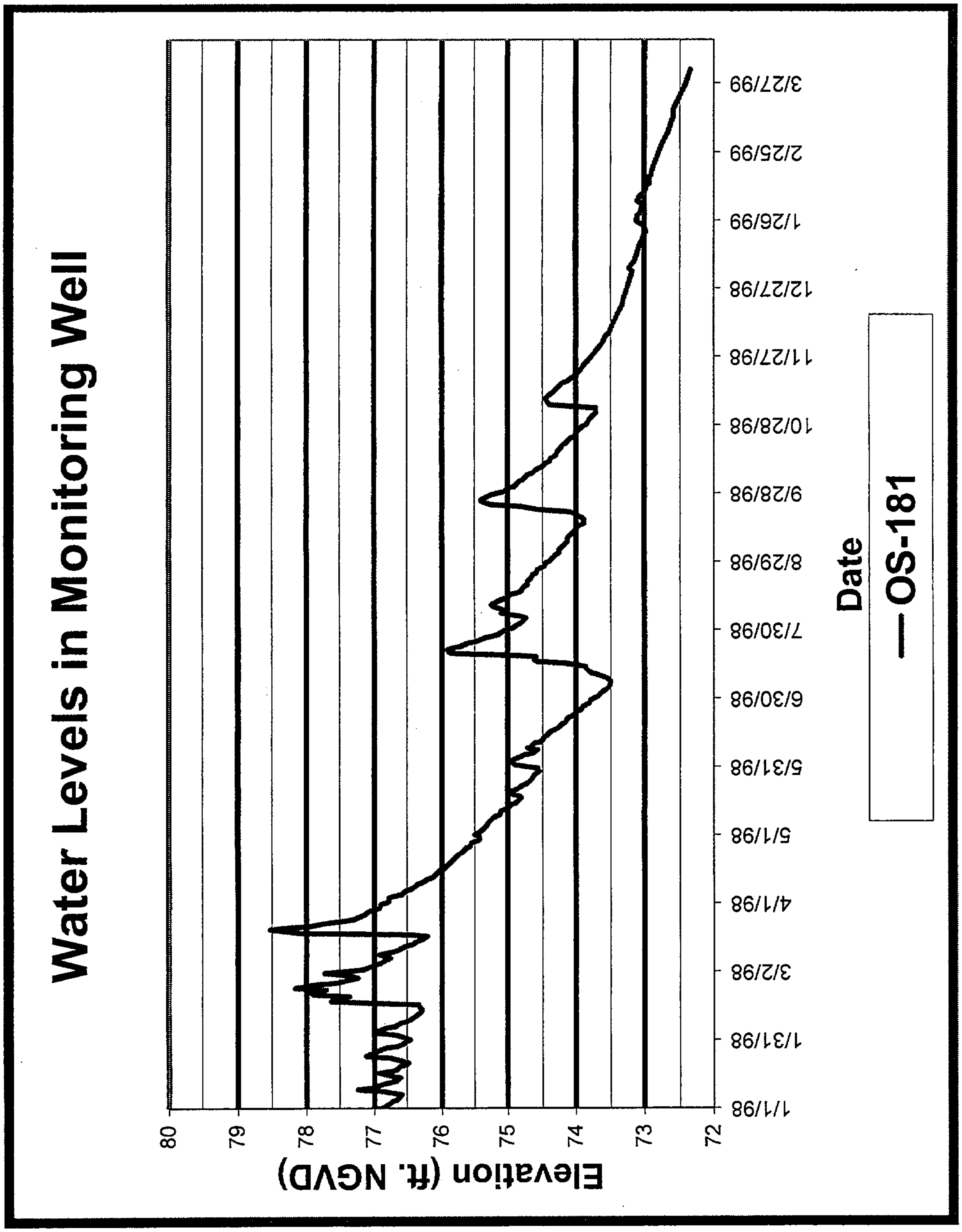
1/1/98
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
10/28/98
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
— Castelli


Water Levels in Monitoring Well
Elevation (ft. NGVD)
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
1/1/98
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
10/28/98
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
— Exotic



Water Levels in Monitoring Well
Elevation (ft. NGVD)
80
79
78
77
76
75
74
73
72
1/1/98
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
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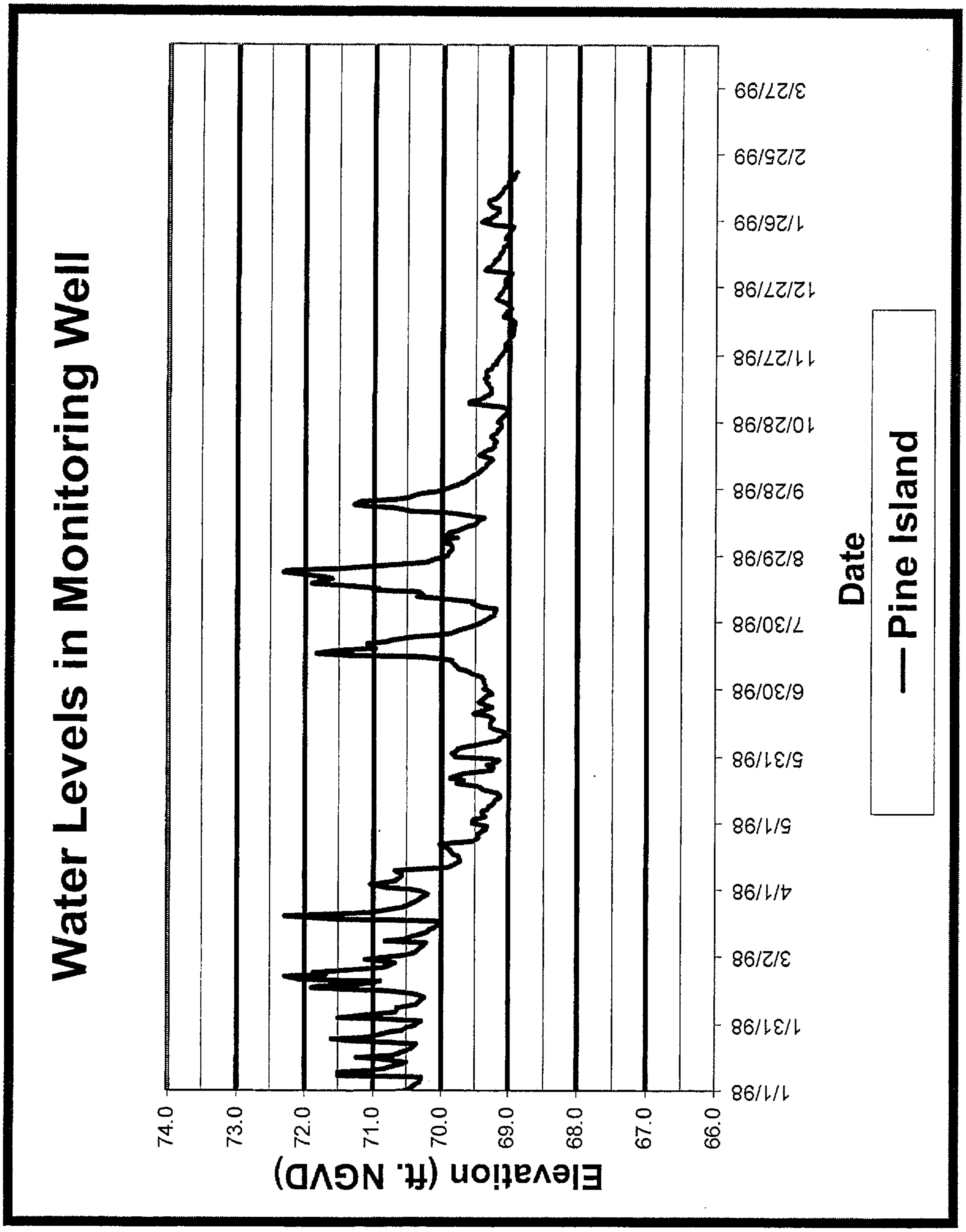
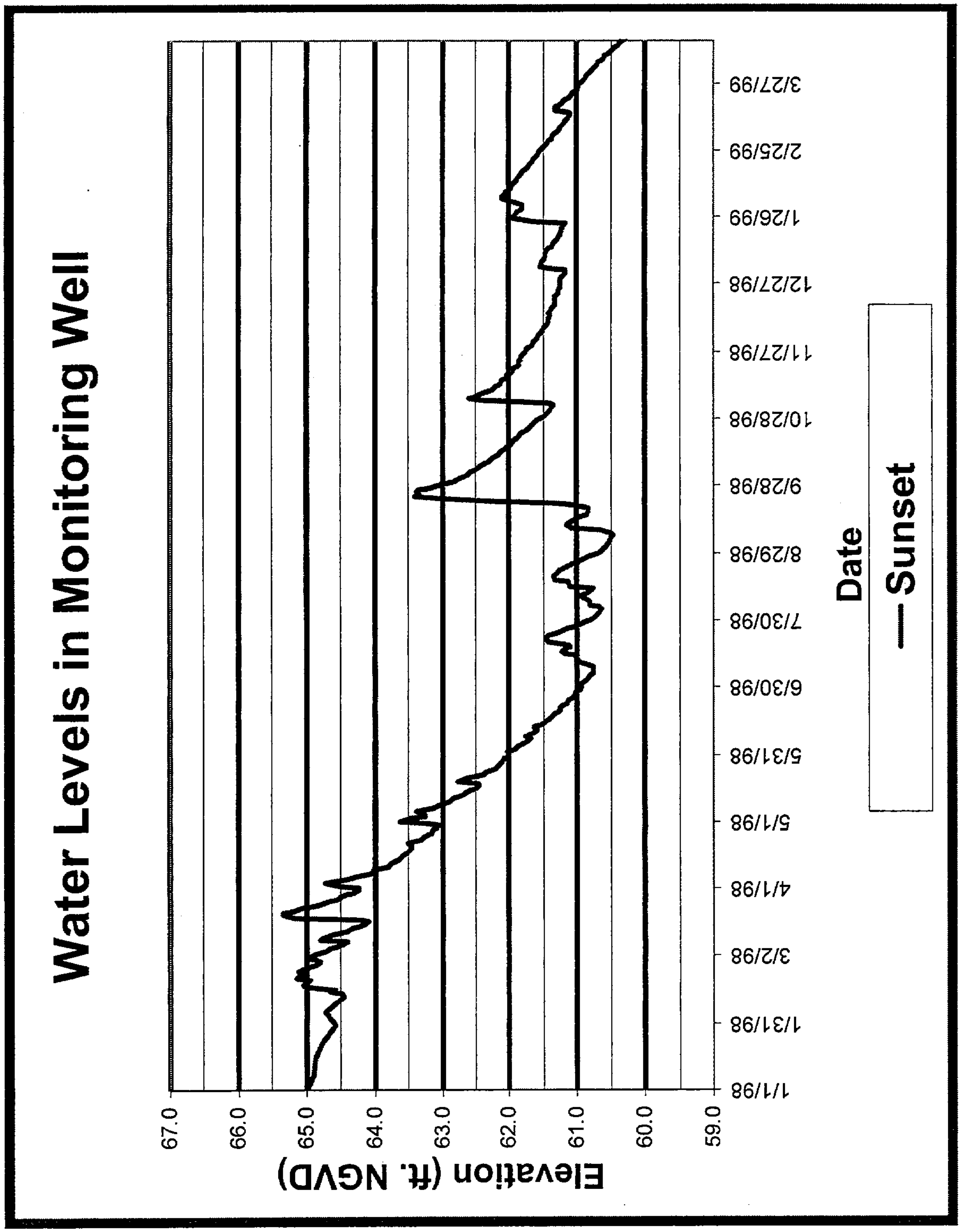
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
—OS-181



Water Levels in Monitoring Well
Elevation (ft. NGVD)
74.0
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
1/1/98
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
10/28/98
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
— Pine Island


Water Levels in Monitoring Well
Elevation (ft. NGVD)
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66.0
65.0
64.0
63.0
62.0
61.0
60.0
59.0
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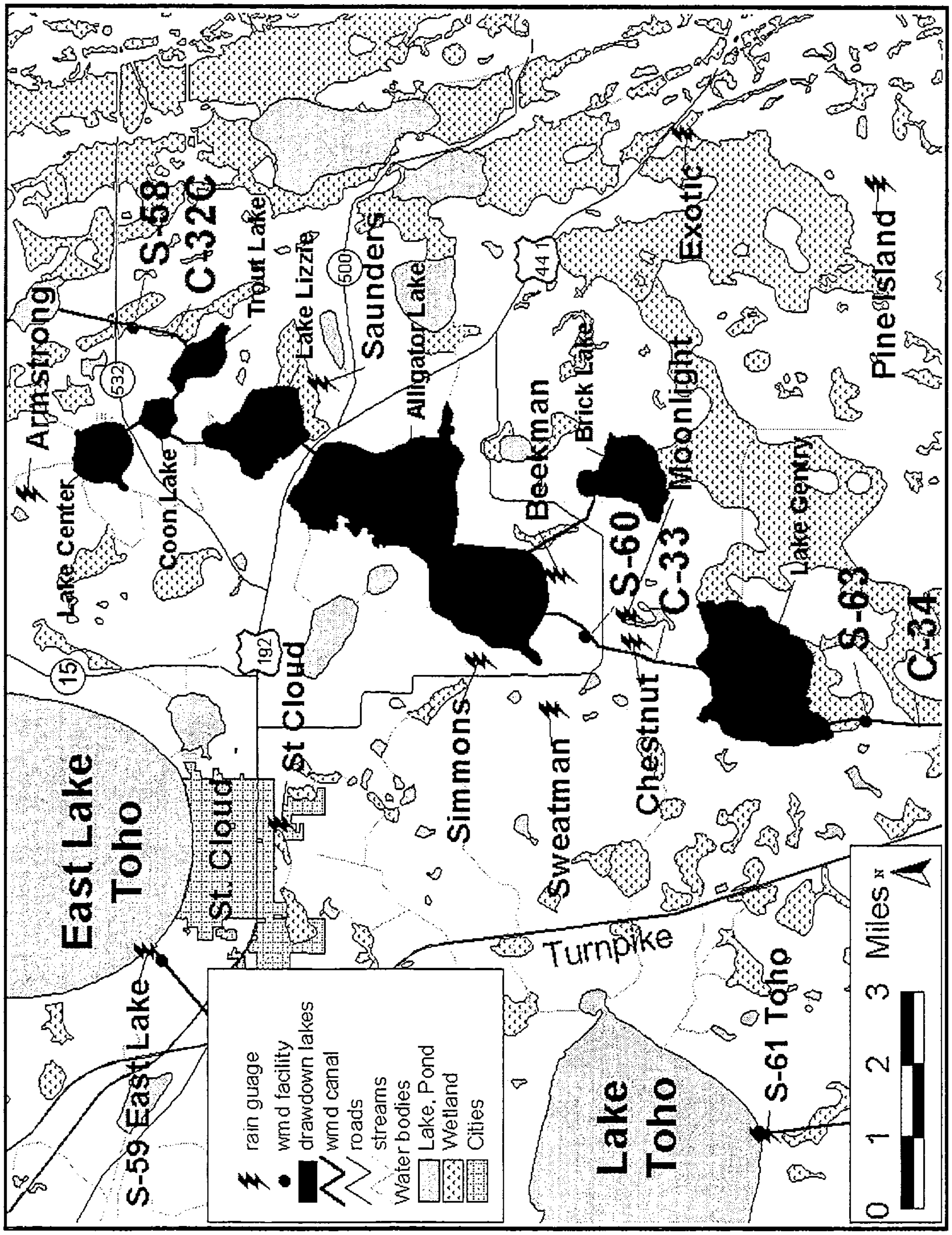
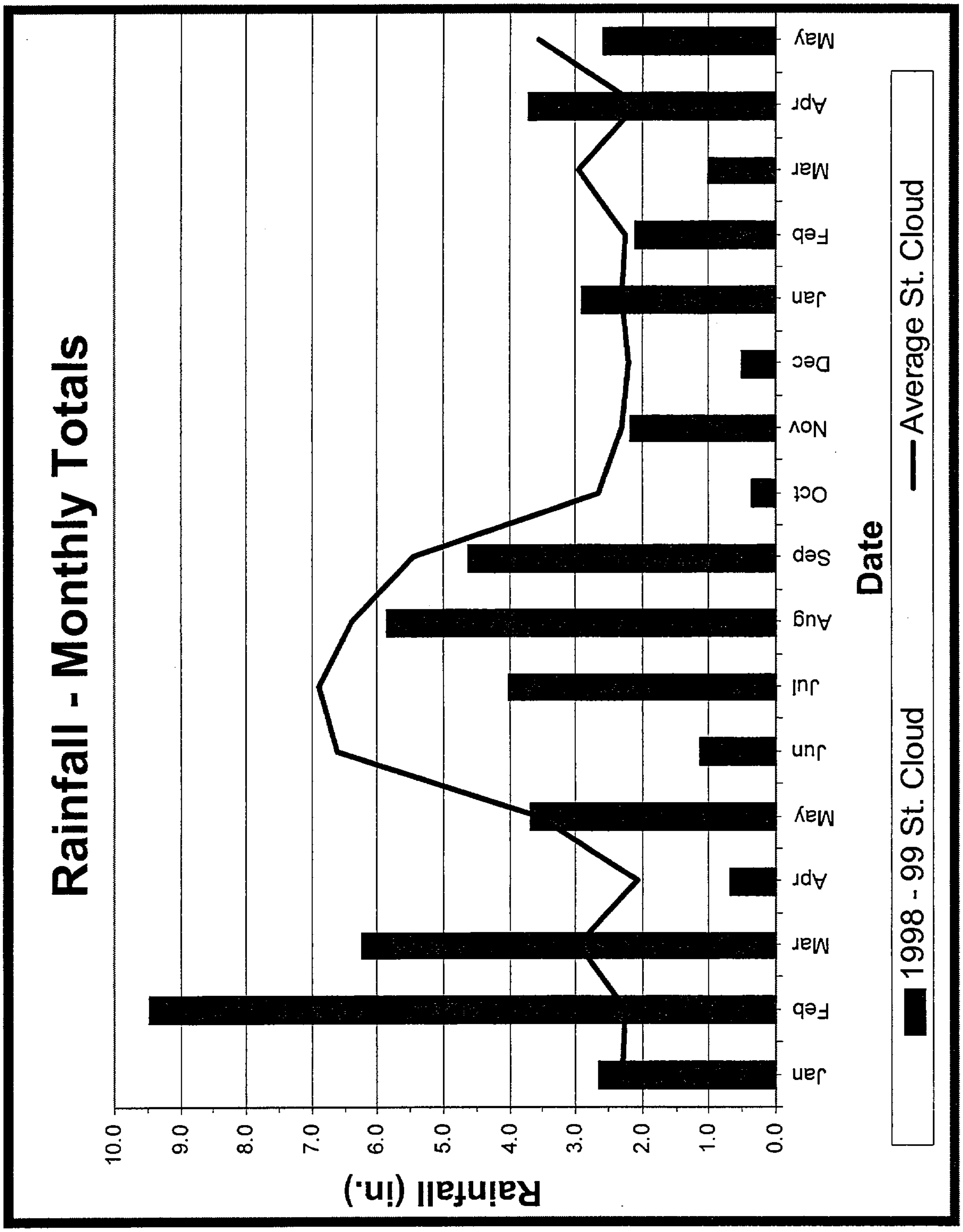
1/31/98
3/2/98
4/1/98
5/1/98
5/31/98
6/30/98
7/30/98
8/29/98
9/28/98
10/28/98
11/27/98
12/27/98
1/26/99
2/25/99
3/27/99
Date
— Sunset

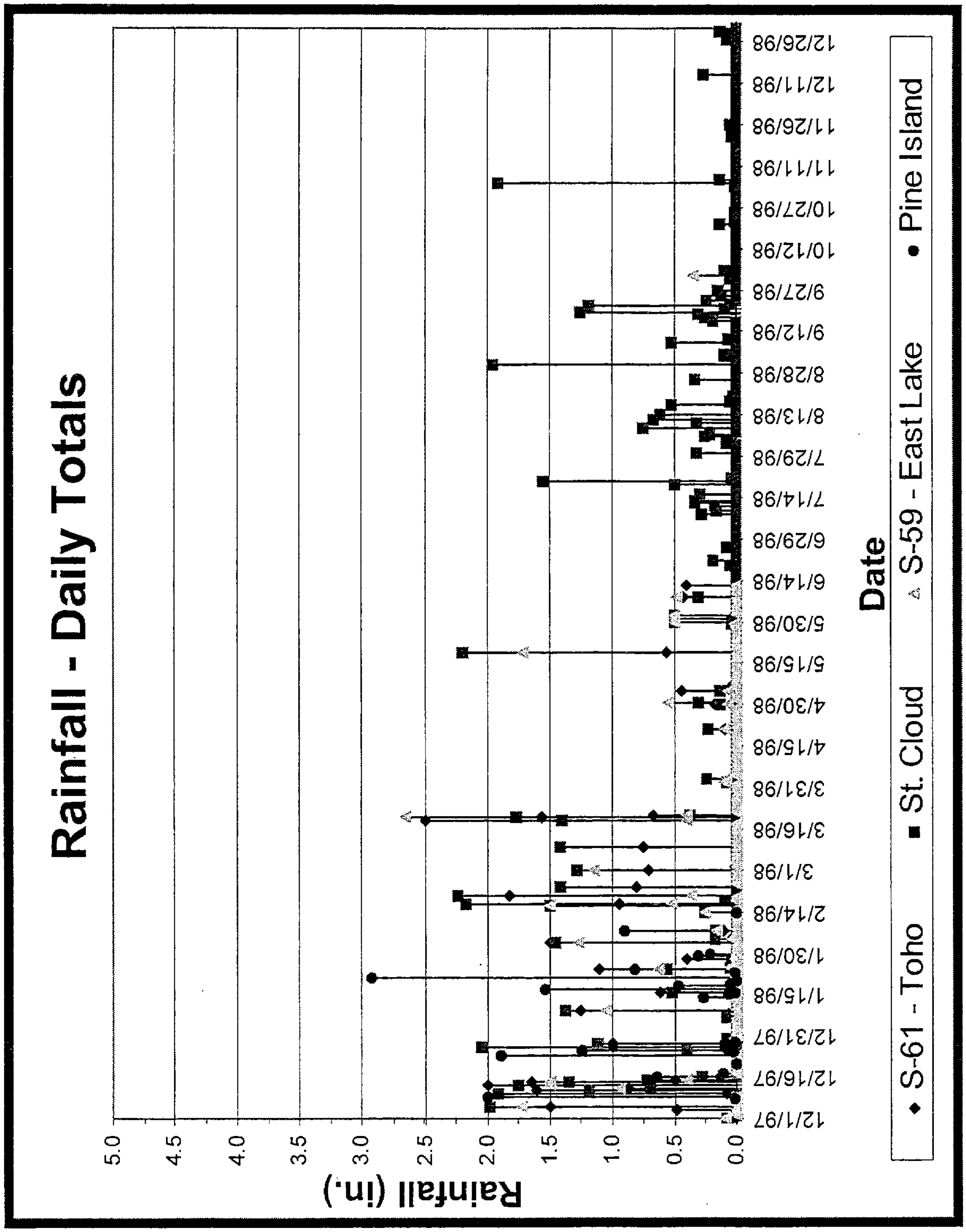
Appendix F. Rainfall Data

Rainfall Data

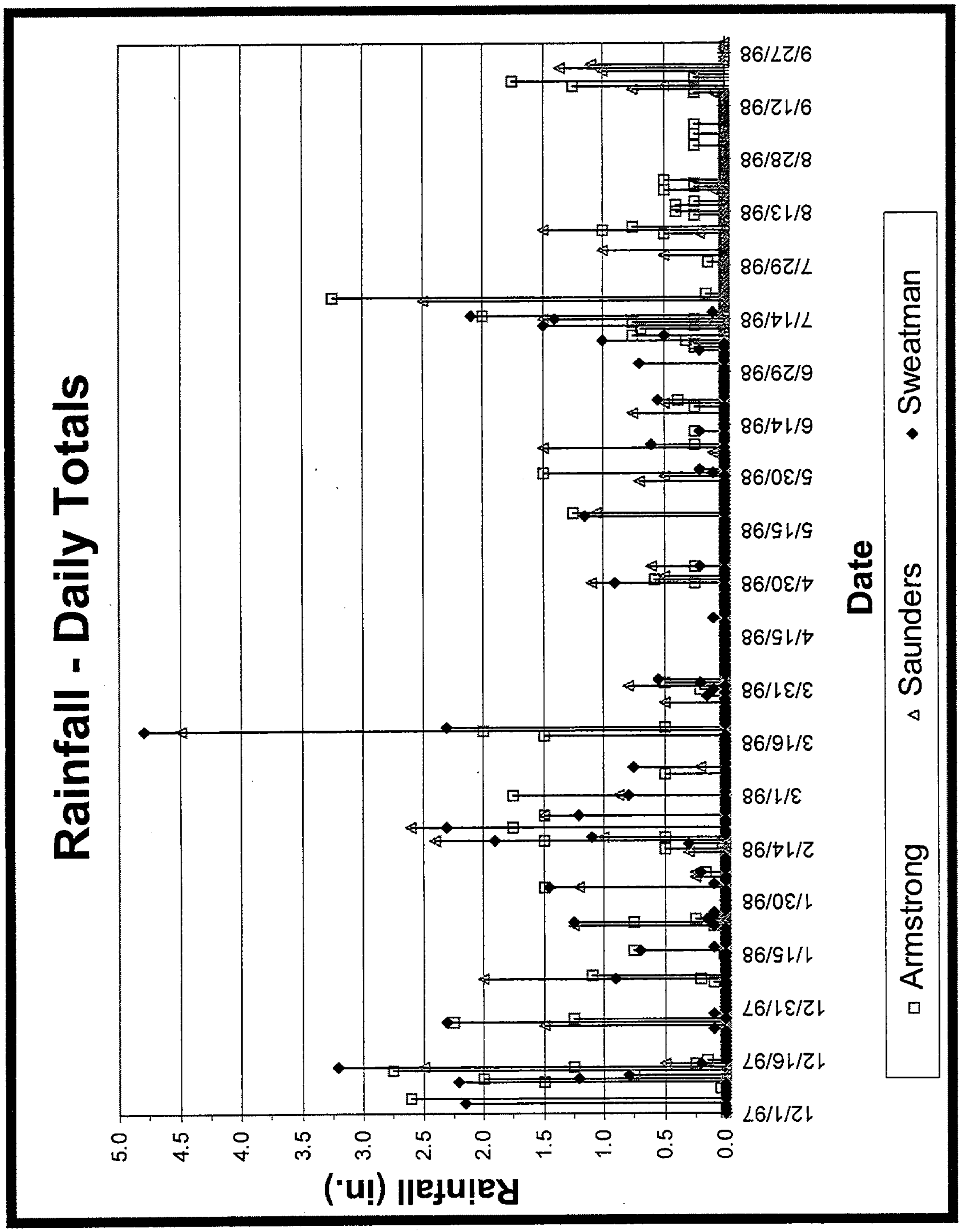
The following graphs show rainfall amounts for selected sites in the Alligator Lake area. They illustrate the variability of rainfall over time and area.

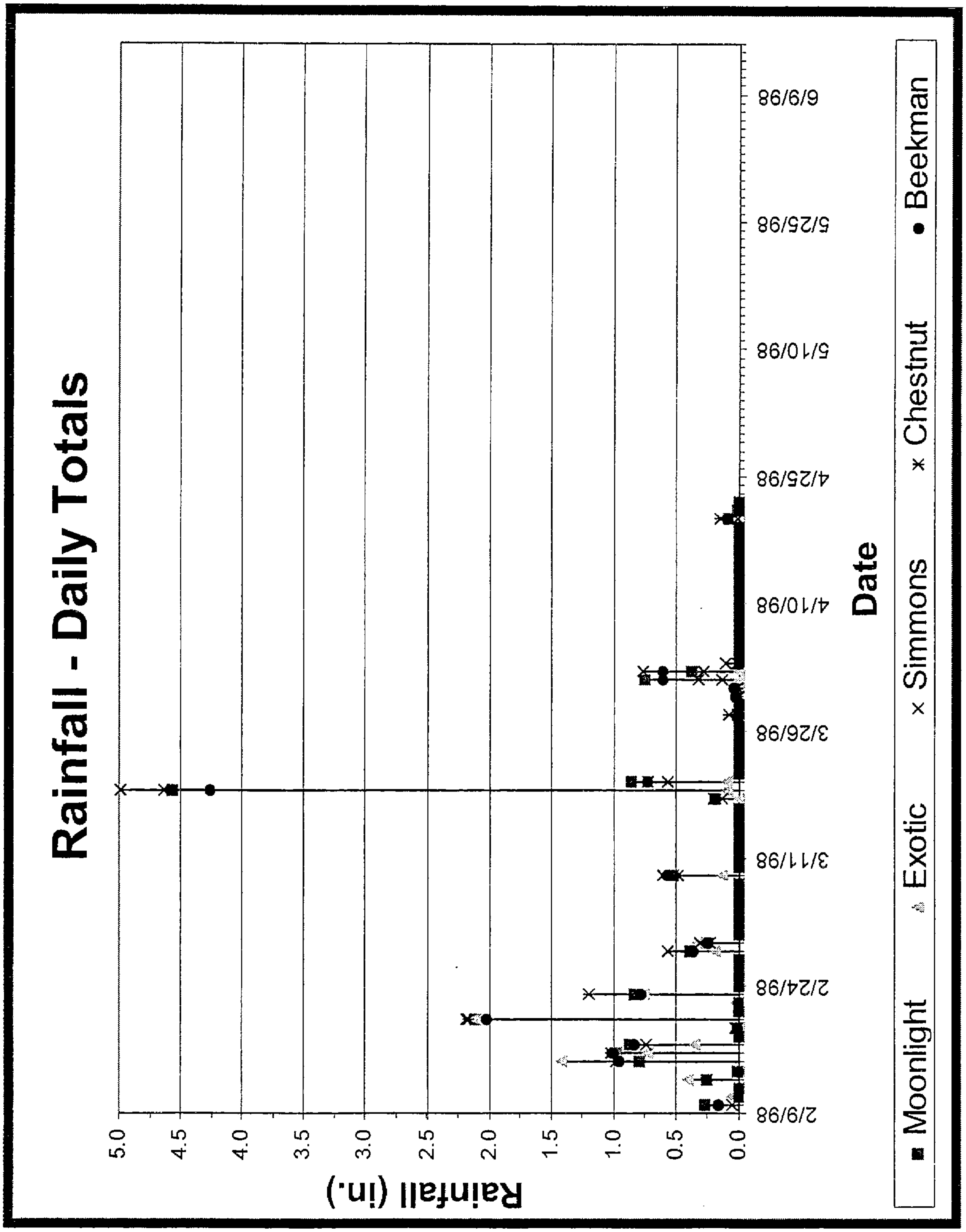

East Lake Toho
St Cloud
St Cloud
Lake Toho
S-59
East Lake
S-61
Toho
Turnpike
15
192
532
500
441
Lake Center
Coon Lake
Armstrong
S-58
C-32C
Trout Lake
Lake Lizzie
Saunders
Alligator Lake
Beekman
Brick Lake
Moonlight
S-60
C-33
Simmons
Sweatman
Chestnut
Lake Gentry
S-63
C-34
Exotic
Pine Island
rain guage
wmd facility
drawdown lakes
wmd canal
roads
streams
Water bodies
Lake, Pond
Wetland
Cities
0 1 2 3 Miles
N


Rainfall - Monthly Totals
Rainfall (in.)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Date
1998 - 99 St. Cloud
Average St. Cloud



Rainfall - Daily Totals
Rainfall (in.)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
12/1/97
12/16/97
12/31/97
1/15/98
1/30/98
2/14/98
3/1/98
3/16/98
3/31/98
4/15/98
4/30/98
5/15/98
5/30/98
6/14/98
6/29/98
7/14/98
7/29/98
8/13/98
8/28/98
9/12/98
9/27/98
10/12/98
10/27/98
11/11/98
11/26/98
12/11/98
12/26/98
Date
S-61 - Toho
St. Cloud
S-59 - East Lake
Pine Island


Rainfall - Daily Totals
Rainfall (in.)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
12/1/97
12/16/97
12/31/97
1/15/98
1/30/98
2/14/98
3/1/98
3/16/98
3/31/98
4/15/98
4/30/98
5/15/98
5/30/98
6/14/98
6/29/98
7/14/98
7/29/98
8/13/98
8/28/98
9/12/98
9/27/98
Date
Armstrong
Saunders
Sweatman



Rainfall - Daily Totals
Rainfall (in.)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2/9/98
2/24/98
3/11/98
3/26/98
4/10/98
4/25/98
5/10/98
5/25/98
6/9/98
Date
Moonlight
Exotic
Simmons
Chestnut
Beekman

Appendix G. MIKE SHE Model Overview

MIKE SHE Model Overview

This appendix provides an overview of the MIKE SHE model used in the analysis of the potential impacts of the Alligator Chain habitat enhancement project. The MIKE SHE model is an integrated hydrological modelling system created by Danish Hydraulic Institute (DHI). Several pages from DHI's internet web site explaining the model are included. They are followed by a description of the data requirements for building a typical MIKE SHE water movement model.

Home | News | Consulting | Software | Research | Courses

- Hydro Informatics
- Ecological Modelling
- Marine Impacts
- Offshore Technology
- Ports& Hydraulic Structures
- Coastal Engineering
- Survey & Monitoring
- River Basin Management
- Flood Management
- River Hydraulics
- Hydrological Modelling
- Water Utilities

Danish Hydraulic Institute's Organisation

About DHI

Danish Hydraulic Institute (DHI) is a research and consulting organisation developing and applying advanced methods and technologies within hydraulic and water resources engineering.

DHI offers a broad spectrum of services, software tools and model test facilities related to offshore, coastal, port, river, water resources, urban hydraulics and environmental engineering.

For DHI it has always been fundamental to establish a thorough understanding of the physics behind the hydraulic phenomena - and then develop the appropriate tools. DHI's consultancy work thus combines sound physical understanding with the most advanced methodologies available. Since the establishment in 1964, projects have been undertaken in more than 120 countries.

DHI is an independent self-supporting organisation. Affiliated to the Danish Academy of Technical Sciences, it is a member of a group of specialised institutes which cover a wide spectrum of applied technologies and engineering services. The DHI staff numbers 235 (1997) of whom two thirds hold PhD or MSc degrees.

Management

Asger Kej, Managing Director
Peter Rasmussen, Finance Director
Jens Kirkegaard, Division Director - Marine Technology
Jacob Steen Møller, Division Director - Marine Environment
Karsten Havnø, Division Director - Water Resources

Divisions	*Departments and Department Heads*
Marine Technology	• Offshore Technology (OTD) - Vagner Jacobsen

- Ports & Hydraulic Structures (PSD) - Jesper Fuchs
- Coastal Engineering (CED) - Ida Brøker
- Survey & Monitoring (SMD) - J Hans Neerings

Marine Environment

- Hydro Informatics Technologies (HIT) - Peter Justesen
- Ecological Modelling (EMC) - Hans Jacob Vested
- Marine Impacts (MID) - Erland B Rasmussen

Water Resources

- River Basin Management (RMD) - Jesper Knudsen
- Flood Management (FMD) - Jacob Høst-Madsen
- River Hydraulics (RHD) - Kim Wium Olesen
- Hydrological Modelling (HMD) - Anders Refsgaard
- Water Utilities (WUD) - Sten Lindberg

Other Contacts

- Business Development - Alan Hooper
- Corporate Development - Jørgen Bo Nielsen
- Research & Development - Jens Christian Refsgaard
- Quality Assurance - Carsten Dahl
- Library - Pia Dynesen

Head Office Hørsholm, Denmark

Subsidiaries and Representations List with adresses and home pages

Hydrological Modelling Department (HMD)

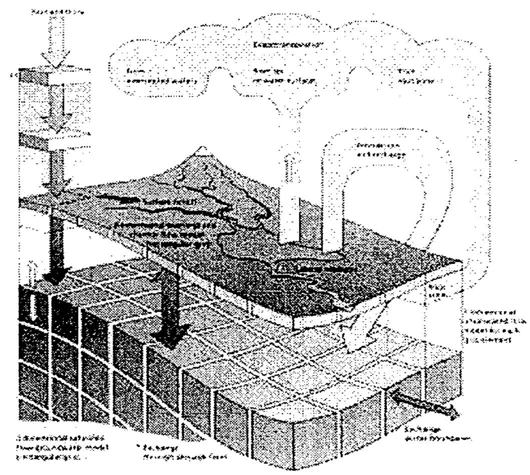
General Description

The Hydrological Modelling Department provides expertise in hydrological models as well as continous development of modelling tools. In a large number of consultancy projects carried out all over the world the department has specialised in integrated hydrological studies focusing on assessment of surface water and ground water resources and their interaction.

The Department has furthermore developed the advanced existing models to encompass the simulation of contaminant transport and the analysis of alternative remedial measures.

In the ongoing development process the software products are applied in both research and consultancy projects. The feedback from field applications ensures that the models are updated to meet user requirements.

The staff of HMD covers the range from research and development to a variety of applications which form the basis for providing not only software products and the expertise in applying those, but also training courses designed for model users.



Areas of Expertise

- development and application of hydrological modelling software systems
- planning and consulting concerning hydrological process studies
- flow, solute transport and water quality in ground water and soils
- interaction between ground water and surface water
- detailed analysis of consequences of water resources exploitation
- analysis of ground water contamination
- design of hydraulic remedial actions against soil and ground water pollution
- leaching, transport and degradation of agrochemicals
- environmental optimisation of the application of agrochemicals considering their interaction with water, soil and crops

Key References

- Danubian Lowland Information System, Slovakia
- ground water management studies for the Counties of Aarhus and Funen, Denmark
- optimisation of water consumption, including irrigation for the province of Dak Lak, Vietnam
- development of a hydrological model for the Everglades, Florida
- Arnitlund, Denmark (1995)

Products

- MIKE SHE WM, AD, ADM, MIKE11
- WATBAL

Key Personnel

- Anders Refsgaard, Head of Department

DHI Software

MIKE SHE

- an Integrated Hydrological Modelling System

As part of DHI's software family MIKE SHE undergoes a continous development process. This involves implementation of more efficient solution methods as well as development of new modules for MIKE SHE. Recently new modules for particle tracking (PT), bio-degradation (BD) has been incorporated and modules for density driven flow and a suite of geochemical processes are under development.

The core of MIKE SHE is the Water Movement module (WM). MIKE SHE WM contains a number of process simulation modules which, in combination, describe the entire land phase of the hydrological cycle:

- Evapotranspiration component (ET)
- Unsaturated Zone flow component (UZ)
- Saturated zone flow component (SZ)
- Overland and Channel flow component (OC)
- Irrigation module (IR)

Based on preceding water movement simulation extensions modules are available for:

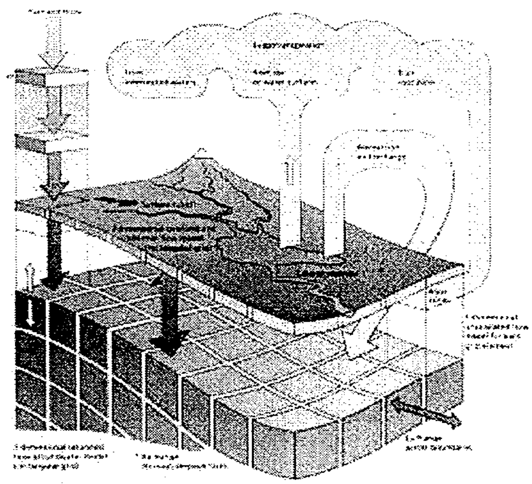
- MIKE SHE AD - solute transport module (advection/dispersion)
- MIKE SHE PT - particle tracking module
- MIKE SHE ADM - adsorption/degradation module
- MIKE SHE GM - geochemistry module
- MIKE SHE BM - biological degradation module

MIKE SHE is operated from a very user friendly environment and supported by efficient Pre- and Post processing facilities (MIKE SHE PP). MIKE SHE PP offers a suite of useful tools such as:

- data manipulation tools including graphical editing facilities
- interpolation and polygon making facilities
- easy and flexible incorporation of geological information
- advanced graphical display facilities including animation of results.
- on-line help facilities and built-in error checking

MIKE SHE PP also includes

routines for water balance calculations on regional and subcatchments scale as well as detailed solutes balance on different scales.



MIKE SHE
Evapotranspiration Module (ET)

Introduction

A part of the rainfall will be intercepted by the vegetation and subsequently lost by evaporation. It is assumed that the interception is either depending on the rainfall rate and/or the interception capacity. The importance of interception depends very much on vegetation type, development stage, density of vegetation and the climatic conditions. Dense forest canopies may account for a considerable interception loss, whereas for shorter and sparser vegetation, such as grass and agricultural crops, the evaporation loss may be much smaller and often insignificant.

Evapotranspiration involves the transfer of large quantities of water. In temperate areas approximately 70% of the annual precipitation is returned to the atmosphere, while under arid conditions it almost equals the rainfall. For this reason the prediction of the actual evapotranspiration plays a key role in many water resources studies.

The evapotranspiration is the total process of evaporation from soil and water surfaces and transpiration, the water uptake by plant roots that is transpired from the leafy parts of the plant. The spatial and temporal variation in the evapotranspiration rate in a catchment depends on multiple factors such as water availability in the root zone, the aerodynamic transport conditions, plant physiological factors etc.

The accumulation of precipitation in snow pack and the release at thaw can be incorporated by a degree-day approach in MIKE SHE SM.

Available methods

At present, two alternative formulations of the interception/ evapotranspiration process are available in MIKE SHE WM.

(a) The Rutter model/Penman-Monteith Equation

The interception is modelled by a modified Rutter model. This calculates the evaporation, the actual storage on the canopy, and the net rainfall reaching the ground surface as canopy drainage and throughfall. The actual evapotranspiration rates are calculated by the Penman-Monteith equation using canopy resistances. The potential evapotranspiration is calculated directly using climatological and vegetation data.

(b) The Kristensen-Jensen model

The interception storage is calculated based on actual leaf area index and an interception capacity coefficient. The net rainfall is calculated by a simple water balance approach.

The actual evapotranspiration is calculated on the basis of potential rates and the actual soil moisture status in the root zone.

Examples of output

The ET component calculates, at each grid square where calculation are performed with the UZ component, time series of e.g. evaporation from interception storage and ponded water, soil evaporation, and transpiration. This is illustrated below.

Animations

see technical info

Karup video

The animation shows spatial and temporal variations in the actual evapotranspiration rate (Ea) in the Karup catchment. The catchment covers an area of 425 km2 and has a single unconfined sandy aquifer. Ea strongly depends on the development stage of the crops and the depth to the ground water table.

MIKE SHE

Unsaturated Zone Module (UZ)

Introduction

The unsaturated zone is a crucial part of the hydrological system in a catchment. It plays an important role in many modelling applications, e.g. for recharge estimation, surface-groundwater interaction and agricultural pollution. The unsaturated zone refers here to the mostly-unsaturated soil profile extending from the land surface down to the groundwater table. The profile is usually heterogeneous, consisting of horizons with distinct differences in the physical properties of the soil.

The unsaturated zone is characterised by cyclic fluctuations in the soil moisture as water is replenished by rainfall and removed from the soil profile by evapotranspiration and percolation.

Percolation may introduce a rise in the water table, whereas upward flow from the groundwater due to capillary rise may occur in areas with a high groundwater table and high evaporation demands.

Unsaturated flow can usually be considered vertical since gravity plays a major role during the percolation of water. The unsaturated flow is therefore only represented in MIKE SHE WM by a vertical flow component, which fulfils the requirements of most situations. However, this assumption may limit the validity of the flow description in some special cases, e.g. on very steep hillslopes with contrasting soil properties in the profile.

A coupling procedure between the unsaturated zone and the saturated zone is has been developed to compute the correct soil moisture and the water table dynamics in the lower part of the soil profile.

Available methods

Two options are available in MIKE SHE UZ :

(a) Richards' Equation

The vertical flow including phenomenas as capillary rise are calculated based on the specified hydraulic conductivity curves and the soil moisture retention curves. In studies with focus on the unsaturated zone this is normally applied.

(b) Gravity flow

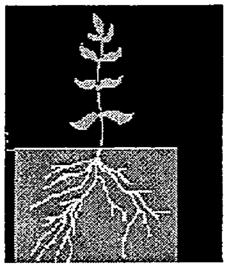
A reduced version assumes a uniform vertical gradient in the soil column and the infiltration and percolation processes are described in terms of gravity flow. When the unsaturated zone is included mainly to provide recharge estimates for the saturated zone this option should be chosen.

Example of Output

The UZ component computes the temporal variation in soil moisture in all nodes above the groundwater table. The infiltration and recharge rate is also calculated.

Animations

see technical info



Irrigation on plot scale

The example is from a plot scale simulation and illustrates the temporal variations in the soil moisture conditions, and evapotranspiration as a function of rainfall, irrigation and crop development.

MIKE SHE
Saturated Zone Module (SZ)

Introduction

The groundwater component is the core of MIKE SHE WM. It computes the transient groundwater flow and Head in a 3D finite difference grid based on the given boundary conditions and the interaction with the other components included in the model.

Groundwater flow plays a significant role in the hydrological cycle. During drought periods it provides and sustains streamflow through baseflow, while during storm events it may contribute significantly to the stormflow as well as influence the magnitude of overland flow provided by the rising water table.

Aquifers in catchments can contain large water resources storage which, besides natural changes, may be subject to abstraction for water supply and irrigation. The influence of this human activity may influence the natural recharge and discharge properties and thereby change the flow regime in the catchment.

Available methods

Two solution techniques are available to solve the equations governing 3-D groundwater flow :

(1) Modified Gauss-Seidel

An implicit, iterative scheme providing a value for the hydraulic head in time at each computational node.

(2) Preconditioned conjugated gradients (PCG)

An implicit, iterative scheme especially efficient for steady state flow and large set-ups.

River-aquifer exchange

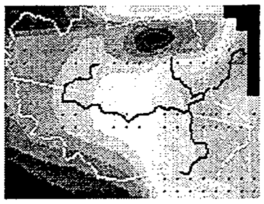
The river system usually affects the groundwater head in both the horizontal and vertical directions, defining the recharge and discharge areas. River/groundwater exchange is accounted for in two ways:

(1) The river is in full contact with the groundwater aquifer

(2) A riverbed lining of low permeability separates the river from the groundwater aquifer.

Animations

see technical info



The objective of the present animation is to illustrate the stream-aquifer interaction and the water balance components in the lower aquifer in a larger ground water resource planning study for the municipallity of Aarhus. The animation shows:

- the temporal variation of the four water balance components in the aquifer, that is abstraction, recharge, baseflow and net Inflow to the aquifer - calculated inside the topographic catchment to a river gauging station
- the spatial variation of heads and flows in the aquifer within the catchment
- a cross-section through the area with the geological settings and variation of heads in the aquifer

MIKE SHE

Overland and River Module (OR)

Introduction

Water accumulated on the soil surface during heavy rainfall or when the groundwater table rises to the ground surface responds to gravity by flowing down-gradient over the land surface en- route to the stream channel system. From here it discharges through the channels (rivers) to the outlet of the catchment.

During its journey to the streams, the flowing water may diminish because of evaporation or infiltrate in areas with more permeable soils.

Available methods

Overland flow velocities and water depths are described by the Saint-Venant equation adopting the Manning formulation for friction slope.

The river flow may be included at two levels of detail and complexity.

1) A 1-D diffusive wave approximation of the Saint-Venant equation

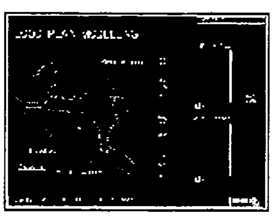
2) Coupling of the MIKE SHE model and the MIKE 11 river hydraulic model. Where floodplains and structures can be included.

Examples of output

The OC component calculates the temporal and spatial ponding depths and flows on the ground surface. In the river system the temporal and spatial variations in water levels and discharge are produced.

Animation

see technical info



Floodplain between Hydro power canal and Old Danube river

The animation illustrates the flooding dynamics on the floodplain and the interaction between surface water (flooding), soil moisture content and ground water levels.

MIKE SHE
Irrigation Module (IR)

Introduction

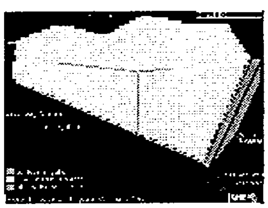
Irrigation of crops accounts for about 70 % of the water use in the world. Many irrigation schemes have a low irrigation efficiency due to inappropriate design, operation and maintenance.

A closer analysis of the irrigation management considering surface and groundwater availability, distributed temporal crop water demand and crop yield is performed by the MIKE SHE Irrigation Component applying MIKE SHE WM exclusively or in combination with the MIKE 11 river hydraulics model.

Available methods

The irrigation component is highly flexible and the avaialble options makes it possible to investigate a wide range of irrigation practices. The irrigation component includes conjunctive use of surface and groundwater with the option of setting priorities. If insufficiencies of e.g. surface water is encountered during the simulation period the model may be set up to automatically shift to abstracting ground water, or vice versa. The irrigation supply may be specified as a pre-defined periodically supply, e.g. by rotation, or controlled by a water demand determined by the actual soil moisture deficit of the root zone.

Animation



see technical info

The aniamtion shows a local scale irrigation scheme including a number of fields, head regulator, main channels, distribution channels and drainage system. Water is supplied by a rotational principle. The water poured on the surface infiltrates and increases the soil moisture content of the root zone. Water absorbed by plants is subsequently lost to the atmosphere by evapotranspiration and the soil moisture content is gradually reduced.

MIKE SHE

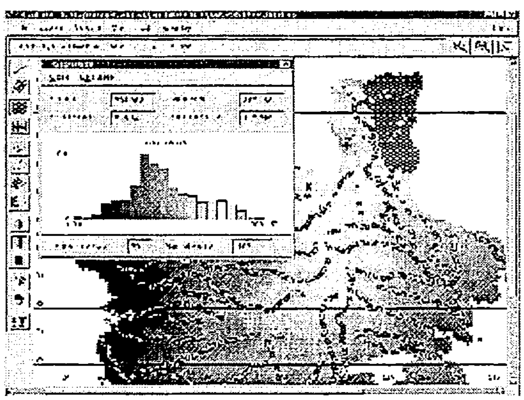
Pre- and Post Processing Module (PP)

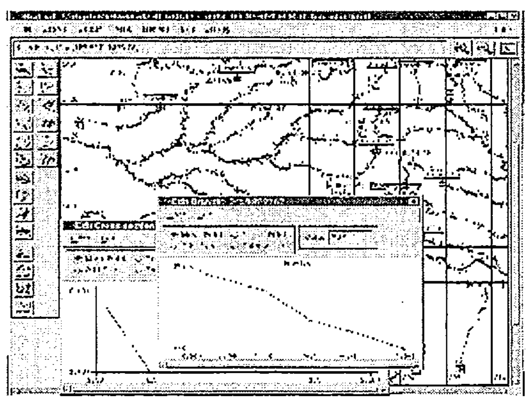
The user interface of the MIKE SHE WM module includes a powerful pre- and post-processing software package which eases the input of data and the analysis of simulation results. The software can be applied to the input data and results of all the MIKE SHE modules.

The user can easily design and produce plots or animations of any variable. This provides a unique opportunity to present the dynamic behavior of the simulated system and adds a new dimension to analysis and interpretation of results.

Some examples of the software capabilities are:

- Digitization of mapped contours, river system and areally distributed data
- Interpolation routines to provide point values and grid averages
- Graphical editing of 2-D data and river data
- Graphical presentation of simulation results in full colour graphics including spatially ditributed maps and time series.
- Plots of the variations in space of a variable in any layer or along any line through the model
- Plots of time series of any variable





DATA REQUIREMENTS FOR BUILDING A TYPICAL MIKE SHE WATER MOVEMENT MODEL

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1 Introduction

MIKE SHE is a generalized physically based modeling system and may be applied to a variety of hydrological studies and to a large range of spatial and temporal modeling scales. MIKE SHE encompasses a number of components describing the flow within different parts of the hydrological cycle. They can be combined depending on the scope of the study. Therefore the term "typical MIKE SHE model" is not easy to define. Primary objectives of the model application may be overall resource assessment of an entire basin or the effect on a state variable (e.g. flow or water level) in a particular location.

The presented guide lines for data requirements applies to an integrated model including the major flow components: MIKE SHE SZ (saturated zone flow), MIKE SHE UZ (unsaturated zone flow), MIKE SHE ET (evapotranspiration module) and MIKE SHE OC (overland and channel flow). Within each MIKE SHE components one or more methods may be available for which the data requirements are different.

It should be pointed out that a number of specialized studies may be undertaken by adding extension modules – the data requirements for such studies is not described in the following. Comments have been added on data requirements for the MIKE SHE/MIKE11 coupling.

MIKE SHE is applied for both large-scale regional studies with a using a spatial discretization in the order of 200-1000 m and time-horizons in the order of 5-50 years and to small-scale local studies focusing on e.g. a wetland or a floodplain of particular interest. In the latter case the spatial resolution may be in the order of 5-50 meters and the time-horizon typically covers a few months or a couple of years.

The spatial and temporal scale of available input data should reflect the purpose of the study and the detail requested of model outputs. Lack of data in a distributed model may imply assumptions on the general validity of extending existing data to the entire model area. Such assumptions affect the uncertainty associated with the model results. It is, however, possible to set up a model based on limited data that may be appropriate for different purposes.

The following provides a brief description of the type of data required for a typical MIKE SHE application. Where possible recommendations on the quantity and quality of data is made. Normally the following distinction is made between inputs to the model:

- Input data (geometry of the hydrological system, field data, etc.)
- Input parameter (hydraulic and hydrological properties)
- Calibration data (observed state variables, e.g. flow or potential head)

Prior to entering the data to the MIKE SHE set-up it must be converted into a common format. Basically two types of data files can be specified (.T2 maps of horizontally distributed data and .T0 files of time series data). Preparing T2-files and T0-files from spreadsheets and GIS coverages is normally easily done and a range of utilities exists to assist the conversion.

MIKE SHE data file formats are described in MIKE SHE Pre- and Postprocessing Manual, Appendix A and further information on model development is found in MIKE SHE WM Short Description and MIKE SHE WM User Guide.

2 Specification of Data Requirements

2.1 Basic data

The basic data required to run any MIKE SHE model is: the extent of the model area, surface topography, and rainfall data.

2.1.1 Model area

The first step in a MIKE SHE model set-up is to decide on the extent of the model area. At the same time a coordinate system must be adopted preferably with an origin referring to the global coordinate system for which most data are available. To the extent possible the model area should be confined by natural boundaries such as water divides (zero-flux boundaries) rivers (head boundaries). In a model including both surface and sub-surface flow the water divides may not coincide. In such cases a potential head boundary or a flux boundary may be required for the groundwater.

The model area may be digitized and stored as xy data in an ASCII file or in an Excel spread sheet. Alternatively the model area may be digitized in ArcView or ArcInfo GIS and stored as a polygon coverage.

If the final extent of the model has not been established all input data should be prepared for an area larger than the model area.

2.1.2 Topographical Information

A topographical map based is produced from interpolation of spot or contour elevation data covering the model area.

Detailed topographical contour maps (1:5000 or 1:10000 with 1-5 m contour intervals depending on overall slope) are digitized. Low-lying areas and highland areas must be represented.

To build a Digital Elevation Model for flood mapping using the MIKE 11 GIS interface, the flood plains must be digitized. To build the DEM inside ArcView spot elevations can be digitized and stored as X,Y,Z in an ASCII file. ARCINFO data can easily be transferred to the ArcView MIKE 11 - GIS interface.

2.1.3 Rainfall Data

All available rainfall data for the selected period from all available rainfall stations in the study area shall be collected and entered in file formats described above. Rainfall data are typically available as daily data. Daily data is sufficiently detailed for a MIKE SHE catchment scale study.

A map showing the location of all the rainfall stations should be made together with a table listing all stations, periods of records and station elevations. Precise location (x-y coordinates) must be known for each station. The coordinates are used to generate polygons, typically Thiessen polygons, for spatial distribution of rainfall data.

Based on mean annual rainfall isohyet maps may be produced to check whether distribution by Thiessen polygons is appropriate.

2.2 MIKE SHE SZ – Saturated zone component

2.2.1 Geology

Geological and data are required to set up MIKE SHE SZ. Based on a conceptual understanding of the groundwater aquifer system a geological model is established. Different types of data may be utilized to describe the major geological units.

Borehole data if often the most important source of information. Lithological classification at a number of geo-referenced boreholes serves as basic data for the geological interpretation. A number of geological units, M, are identified and the data may be organized in a spread sheet for the boreholes 1..N as:

Borehole ID 1
Ground surface elevation at borehole
Z of lower level, Unit 1
Z of upper level, Unit 2
Z of lower level, Unit 2
Z of upper level, Unit 3

.
.

Z of lower level, Unit M
Borehole ID 2

.
.
.

Borehole ID N

where Z is the depth below ground surface or the elevation.

Or the data may be organized in a number of xy files. One for the upper and lower side of each geological unit:

xy file 1 (elevation of lower level, Unit1)
$X_{borehole1}$ $Y_{borehole1}$ $Z_{borehole1}$
$X_{borehole2}$ $Y_{borehole2}$ $Z_{borehole2}$
. . .
. . .
$X_{boreholeN}$ $Y_{boreholeN}$ $Z_{boreholeN}$

xy file 2 (elevation of upper limit, Unit2)
.
.
.
xy file 2 (elevation of lower limit, Unit M)

If geophysical data (electromagnetic resistance) exist for the model area the could be prepared as xyz-data for depth intervals.

2.2.2 Hydrogeology

The hydraulic properties of aquifers, aquitards and aquicludes must be specified in terms of horizontal conductivity, vertical conductivity, confined storage coefficient and unconfined storage coefficient. These parameters are normally derived from pump test analysis.

Transmissivity or storage coefficient data may be organized as xyz data with Z as transmissivity or storage coefficient, respectively. If the data density is high interpolated maps may be produced by the MIKE SHE interpolation utility.

2.2.3 Abstraction data

Groundwater abstraction data must be prepared in terms of well location (xy coordinates) and time series of abstraction data covering the simulation period. Data on monthly basis are normally sufficient to describe the annual variation. Abstraction time series must be prepared in two spreadsheets as :

1) Well location :

Well1	X_{well1}	Y_{well1}	$Z_{up.screen}$	$Z_{low.screen}$	*'Well ID1'*
Well2	X_{well2}	Y_{well2}	$Z_{up.screen}$	$Z_{low.screen}$	*'Well ID2'*
.	.	.	.	.	
WellN	X_{wellN}	Y_{wellN}	$Z_{up.screen}$	$Z_{low.screen}$	*'Well IDN'*

2) Abstraction time series:

year1 month1 day hour minute	*abs.rate-well1*	*abs.rate-well2*	. .	*abs.rate-wellN*
year1 month2 day hour minute	*abs.rate-well1*	*abs.rate-well2*	. .	*abs.rate-wellN*
. . . . .	.	.		.
. . . . .	.	.		.
yearM month12 day hour minute	*abs.rate-well1*	*abs.rate-well2*	. .	*abs.rate-wellN*

Time series data are applied 'backwards'. An abstraction specified at e.g. (1998 6 1 0 0) is applied between the previous value in the time series until the June 1 1998.

2.3 MIKE SHE UZ – Unsaturated zone component

The data requirements for MIKE SHE UZ depend on the method to be applied. The available methods are:

- Richardson
- Gravitational flow

The Richardson method is applied when a detailed description of the water content profile is required e.g. as part of studies focusing on the root zone and transpiration. If the capillary potential gives rise to significant exfiltration the Richardson method should be adopted. If on the other hand the primary purpose of including MIKE SHE UZ is to provide recharge estimates to the groundwater the simpler 'gravitational flow' option should be applied.

2.3.1 Soil map and soil profiles

MIKE SHE UZ simulates the unsaturated vertical flow through a number of soil columns found in the model area. Based on soil profiles describing the soil types of the upper meters – from the ground surface to the ground water table – a number of characteristic soil profiles are defined. Soil maps are required to determine the distribution of characteristic soil columns within the model area.

2.3.2 Soil physical data

Soil physical data must be provided for each soil type included in the soil profiles. Retention data and hydraulic conductivity data are needed. The soil physical data required are:
K_s : Saturated hydraulic conductivity (m/s)
θ_s : Saturated water content (%)
θ_r : Residual water content (%)
θ_{eff} : Effective water content (%), air entry water content (maximum achievable water content)
pF_{fc} : Capillary potential at field capacity
pF_w : Capillary potential at wilting point
n : exponen of conductivity curve: $K(\theta)=((\theta - \theta_r)/(\theta_s-\theta_r))^n$

PF is defined as $\log_{10}(-\psi)$ where the unit of the capillary potential, ψ, is cm.

It is recommend entering retention curve data and hydraulic conductivity data into the MIKE SHE soil database. A variety of soils collected during previous studies can be made available to supplement measured data of the model area.

The basic ASCII format of the soil database is :

```
Sandy clay loam        (soil type name)
(depth 0.25-0.70 m,  Seven Creek )    (soil sample location)
     .348500   (θs)
     .348500   (θeff)
     1.30000   (pFfc)
     4.20000   (pFw)
     6.00000
     .900000E-01 (θr)
     18.8000   (n)
     .100000E-04 (Ks)
 15    (number of datasets of retention curve)
     .349100        -2.00000   (water content  -  pF value)
     .348800        -1.00000
     .348500         .000000E+00
     .347100         .100000
     .345000         .200000
     .338700         .500000
     .329000         1.00000
     .303000         1.50000
     .259000         2.00000
     .236000         2.50000
     .212000         3.00000
     .117000         4.20000
     .349000E-01       6.00000
     .349000E-02       6.95000
     .349000E-03       7.00000
```

When the 'gravitational flow' option is applied only K_s, and corresponding values of θ- pF at wilting point, field capacity and saturation are required.

2.4 MIKE SHE OC – Overland and channel component

MIKE SHE OC simulates overland and river/channel flow. Overland flow is calculated from the surface slope that is described through the topographical input map.

To describe river flow the MIKE SHE river flow routine may be applied. Alternatively, for more advanced studies focusing on river hydraulics or flood plain modeling MIKE11 may be used.

Available methods:
- MIKE SHE OC
- MIKE SHE/MIKE11 coupling

2.4.1 MIKE SHE river data

Main channels, rivers and tributaries are digitized and prepared in xy ASCII format for the MIKE SHE Graphical River Editor. Riverbank elevations are added in a number of points along the river reaches. Data may be organised from upstream to downstream of each river reach as:

x_1	y_1	$Zbank_1$
x_2	y_2	*-999.0 (elevation not specified)*
x_3	y_3	$Zbank_3$
.	.	.
.	.	.
x_N	y_N	$Zbank_N$

All cross sections are prepared as :

20 (Manning number, $m^{1/3}/s$)
1e-008 (Leakage coefficient, 1/s)

-0.5	*0*	(X-value (m), Depth (m))
-0.25	*-0.5*	
0.25	*-0.5*	
0.5	*0*	

2.5 MIKE SHE SM

2.5.1 Temperature Data

Temperature data are only included when simulations of snow melt is required. Dates are specified on daily basis. The unit (°C) is applied.

2.4 Time Series Data Format

Data records are easily transferred to MIKE SHE data bases via ASCII text files or EXCELL spread sheet files. The data format for all MIKE SHE time-series consists of a date in terms of separate columns of year, month, day, hour and minute followed by the data value.

Temperature data are only included when simulations of snow melt is required. Dates are specified on daily basis.

2.6 MIKE SHE ET

Available methods:

- Kristen & Jensen
- Pennmann-Monteith (not in the user-interface)
- Wetland

2.6.1 Evaporation Data

Potential evaporation rate data from available stations shall be collected for the period (e.g. pan evaporation data). The data should preferably be available on daily basis. A monthly frequency is often sufficient to describe annual fluctuations. The location of the evaporation stations must be known and could be shown on the same base map as the rainfall stations. The unit (mm/h) is applied in MIKE SHE formatted files.

2.6.2 Landuse

To simulate the actual evapotranspiration the vegetation distribution must be specified. One or more landuse map based on field surveys, aerial photos or satellite images may be applied to map the characteristic vegetation of the model area. The vegetation applied should reflect differences in evapotranspiration. The vegetation types should include crops, other types of vegetation and areas with no vegetation. The latter category may be subdivided into water bodies, urbanised areas (paved areas) and so on.

If significant landuse changes have taken place within the simulation period more maps of vegetation distribution should be prepared. ArcView polygon data are suitable for generating the required input maps.

2.6.3 Vegetation parameters

The evapotranspiration routine applies vegetation specific parameters. The leaf area index (LAI) describes the leaf area of a unit surface area and the root distribution function describes the root mass as a function of depth. Both values may be measured in the field or found in literature for each vegetation type.

LAI and RDF are time varying and subsequently time series describing the vegetation stages must be provided. On cropped areas an annual cycle of the parameters may be applied while e.g. coniferous forest, evergreen plants or grass areas may be described by constant values.

2.7 Calibration and validation data

Prior to application of the model it is necessary to calibrate and validate it. It is a process of adjusting model parameters to minimize the deviation between simulation results and field observations. A number of calibration references in terms of time series are required.

The model may be calibrated against:

- Potential head of the saturated zone

- River discharge
- Water levels
- Water contents of the unsaturated
- Flood maps

It is recommended to collect data for as long a period as possible. Historical data may often provide useful information on system dynamics and stress responds. A MIKE SHE model should be calibrated against data for a period of years. A typical calibration period is in the order 3-10 years where e.g. wet and dry years are represented. After calibration the model should be validated on data outside the calibration period (split sample test). A validation period should be of the same length as the calibration period. Thus data for a 6-20 year period is typically required in order to calibrate and validate a MIKE SHE model.

It is important that all water level refer to the same datum level (preferably meters above mean sea level).

2.7.1 Potential head data

Data are collected from all observation wells the model area. Ideally the wells should be distributed across the model area and screened to provide potential heads of all major aquifers. Coordinates and elevation of each observation well must be provided. The frequency of recorded levels should be sufficient to account for the time scale of groundwater variations. In most cases monthly values are sufficient but to calibrate against relatively rapid changes caused by e.g. frequent stop and start of pumps the frequency may have to be increased. The dat should have the following format:

1) Observation well location :

Well1	X_{well1}	Y_{well1}	$Z_{up.screen}$	$Z_{low.screen}$	*'Well ID1'*
Well2	X_{well2}	Y_{well2}	$Z_{up.screen}$	$Z_{low.screen}$	*'Well ID2'*
.	.	.	.	.	
WellN	X_{wellN}	Y_{wellN}	$Z_{up.screen}$	$Z_{low.screen}$	*'Well ID3'*

10

2) Abstraction time series:

year1 month1 day hour minute pot. head-well1 pot. head-well2 . . pot. head-wellN
year1 month2 day hour minute pot. head-well1 pot. head-well2 . . pot. head-wellN

. . . .
. . . .

yearM month12 day hour minute pot. head-well1 pot. head-well2 . . pot. head-wellN

2.7.2 River discharge and water levels

All available water level and discharge data for the period from all water level and discharge stations in the study area are required. The flows are normally given in m^3/s. The data are entered in one or more files as:

1) Gauging station location:

Qstation1	X_{qstat1}	Y_{qstat1}	*'Q-station1 ID'*
Qstation2	X_{qstat2}	Y_{qstat2}	*'Q-station2 ID'*
. .	.	.	.
QstationN	X_{qstatN}	Y_{qstatN}	*'Q-stationN ID'*

2) Measured flow time series :

year1 month1 day hour minute Q-stat1 Q-stat2 . . Q-statN
year1 month2 day hour minute Q-stat1 Q-stat2 . . Q-statN

. . . .
. . . .

yearM month12 day hour minute Q-stat1 Q-stat2 . . Q-statN

3 Summary

A short list of data requirements can be found in (Storm B., 1994):

Data and parameter requirements for each grid square or channel link	
Frame	
Input data	Horizontal discretization Ground surface elevation Distribution codes for rainfall and meteorological stations
Interception	
Model parameters (Rutter Model) (for each crop type)	Canopy drainage parameters Canopy storage capacity (time varying) Ground cover indices (time varying)
Model parameters (K-J model) (for each crop type)	Leaf area index (time varying) Interception capacity coefficient
Input data	Rainfall rate
Evapotranspiration	
Model parameters (P-M equation)	Canopy resistance Aerodynamic resistance Ground cover indices (time varying) Ratio between actual and potential evapotranspiration as a function of soil moisture tension Root distribution with depth
Model parameters (K-J model) (for each crop type)	Empirical constants describing the ration between actual and potential evapotranspiration as function of soil moisture Leaf area index (time varying) Rooting depth (time varying) Root distribution coefficient
Input data	Meteorological data
Overland and channel flow	

Data and parameter requirements for each grid square or channel link

Model parameters	Strickler roughness coefficients for overland and river flows Detention storage capacity on ground surface Coefficients of discharges for weir formulae
Input data	Specified levels and flows at boundaries Man-controlled discharges Topography of overland flow plane and river cross sections Riverbed lining thickness Riverbed lining permeability
Unsaturated zone	
Model parameters (for each soil type)	Soil moisture tension/content relationship Unsaturated hydraulic conductivity as a function of soil moisture content Maximum bypass ratio of net rainfall
Input data	Distribution codes for soil profiles Distribution codes for soil types in soil profiles Vertical node discretization in UZ
Saturated zone	
Model parameters	Storage coefficients Saturated hydraulic conductivities Drainage depth Time constant for drainage routing
Input data	Specified flows, gradients and heads at boundaries Location of abstraction or recharge wells Pumping and recharge rates Vertical node discretization in SZ
Snow melt	
Model parameters	Degree-day factor Snow zero plane displacement Snow roughness height
Input data	Meteorological and precipitation data

4 References

Storm B., MIKE SHE WM – Water Movement Module – A Short Description, Danish Hydraulic Institute, Hydrological Modelling Department, 1994

MIKE SHE Pre- and Post-Processing Manual, Danish Hydraulic Institute, Hydrological Modelling Department, 1998

MIKE SHE WM Manual, Danish Hydraulic Institute, Hydrological Modelling Department, 1998

Appendix H. Model Documentation - Spring 1998

Model Documentation - Spring 1998

1 INTRODUCTION

This report documents the construction and calibration of a groundwater model developed for the Alligator Lake drawdown study. The model was constructed using the MIKE SHE code developed by the Danish Hydraulic Institute (DHI). This code was chosen because it allows detailed evaluation of groundwater flow, but is capable of simulating flow in surface waters and the unsaturated zone as well. Initial set-up of the model for the Alligator Lake study was carried out by Mr. Jesper T. Kjelds and Mr. Henrik R. Sørensen of DHI in November 1997. This document describes that work, and modifications made by SFWMD staff during model calibration.

1.1 Background

In order to improve aquatic habitat for fish and wildlife, the Florida Game and Fish Commission and the SFWMD, in cooperation with several other agencies, plan to carry out a drawdown of the water levels in the Alligator Chain of Lakes and Lake Gentry from normal regulation stages to a temporary level of 60 feet and 56.5 feet respectively. Stages in the lakes would held at those levels for three months while muck and plant removal was carried out. In order to assess impacts on water interests (mainly exotic fish farms) around Alligator Lake, an integrated hydrological model based on the MIKE SHE modeling system was established.

The objective of the present Alligator Lake drawdown modeling study is to quantify the impact of the lake drawdown, on ground water levels at selected locations around Alligator Lake assuming different climatic scenarios. These scenarios are defined on the basis of historical and statistical meteorological data and include a dry year, a wet year and a normal year described in terms of amount of rainfall and potential evapotranspiration. The model was calibrated at a daily stress period for the time period November 1997 – June 1998.

2 MODEL FORMULATION

The present chapter contains a brief description of the established models as well as of the data basis of the models. The MIKE SHE WM module provides an integrated description of the hydrologic processes within the catchment area. The established MIKE SHE model includes the following MIKE SHE simulation modules:

- Evapotranspiration
- 2D overland flow and 1D channel flow
- 1D unsaturated flow
- 3D ground water flow

2.1 Catchment Definition

The catchment delineation and characteristics defines the basic geometry of the model area and the rainfall pattern and rates within the model area. Catchment geometry and rainfall rates are considered basic input parameters in MIKE SHE and must always be specified independent of the MIKE SHE simulation modules that are applied.

2.1.1 Catchment Geometry (Catchment Area)

The extent of the model area is shown in Figure 1 on page H-5. Along the northern boundary the model area follows sub-basin boundaries (topographic watershed), while the southern boundary has been chosen rather arbitrarily to include Lake Gentry and encompass all pertinent fish farms.

The model area is discretized in a network of 100 x 125 square grids each having a dimension of 200x200 meters (656.2 ft.). The origin of model area (lower left corner) is (410,104.980 : 1,375,000.000 ft.) in the Florida State planar coordinate system. Converted to the metric system applied in MIKE SHE this corresponds to (125,000.00 : 419,100.00 meters). In MIKE SHE the catchment definition consists of a catchment grid file which defines the horizontal extent of the catchment area and of a surface topography file. MIKE SHE grid files have the default extension ".T2" (T2-files) and may contain integer or floating point values. A catchment grid file is an integer code file.

2.1.2 Precipitation Stations

Time-series of rainfall rates are specified in a MIKE SHE T0 file. ".T0" is the default extension for a MIKE SHE time-series file. There are two active long-term rain stations in the vicinity of the model area, Pine Island and St. Cloud. Ten short-term, hand collected, rain stations were installed in November 1997 to provide local rainfall data for this project. In February 1998, four tipping rain buckets were installed to provide continuous rainfall data. After the tipping rain buckets came on line, only the manually collected data from the Armstrong and Saunders Stations continued to be used. Missing data was filled with observations from the nearest station. The rainfall was distributed in the model using the Thiessen polygon method (see Figure 2 on page H-6).