Coastal Zone Management Program

CHEATHAM ANNEX PROJECT

DEPARTMENT OF ENVIRONMENTAL SCIENCES
UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VA 22903

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Department of Environmental Sciences
University of Virginia
Charlottesville, VA 22903

Submitted to Virginia Department of Waste Management

November 19, 1990

Janet S. Herman
George M. Hornberger
Aaron L. Mills
J. Robert Hoelscher
Scott C. Brooks
Alison E. Clark
Charles H. Hall

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ADDENDA AND ERRATA

Department of Environmental Sciences
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Revisions to Chapter 2: HYDROLOGY

The hand-augered well installation can be more completely described than was done on page 10 in our report. Each hole was hand augered to the total depth listed in Table R1. PVC pipe of the diameter listed in Table R1 was perforated with a power drill at one end of the pipe section for a length listed in Table R1. The perforated portion of the pipe was wrapped in nylon screen. The bottom end of the pipe was capped. The pipe was placed in the hole, and, thus, the screened interval is from the total depth of the hole to the distance of the screened length toward the ground surface. The well was finished off as described on page 10.

Table R1. Well installation details.

Well Name	Casing Diameter (inches)	Total Depth (m)	Screened Length (m)
UVALP-3	1	1.32	0.52
UVALP-4	1	0.87	0.38
UVALP-5	1	1.32	0.37
UVAPZ-1	1	2.53	0.30
UVAPZ-2	1	4.88	0.30
UVAPZ-3	1	6.71	0.30
UVAPZ-4	1	2.74	0.30
UVANW-1	1	0.48	0.30
UVANW-2	1	1.04	0.30
UVANW-3	1	2.18	0.30
UVANW-4	1	1.52	0.30
UVANW-5	1	2.44	0.30
UVANW-6	1	1.05	0.30
UVANW-7	1	0.65	0.30
UVANW-8	1	1.08	0.30
UVANW-9	1	0.69	0.30
UVANW-10	1	0.84	0.30
UVANW-11	1	1.38	0.30
UVANW-12	2	0.84	0.40
UVANW-13	2	0.80	0.40
UVANW-14	2	0.76	0.40
UVANW-15	2	0.73	0.40

Soil moisture potential in the vadose zone is related to the water content of the soil. Soil moisture potential measurements were made in the field as part of this study using a tensiometer. Strictly, a tensiometer measures the matric potential of a soil for soil suction values between 0 and 1 bar. The tensiometer consists of a porous cup attached to the bottom of a rigid plastic tube. The measuring device connected to the tensiometer is the pressure transducer. The electrical output from the transducer was recorded by the data logger. An excellent source of detailed information on this device is available in Morrison, R.D., Ground Water Monitoring Technology: Procedures, Equipment, and Applications, published by TIMCO Mfg., Inc.

Please note that there is also a misspelling on page 10. The reference tensiometer was used for removing temperature biases (not "beases").

The location of the seepage meters:
 Seepage meter 1 at Station 1
 Seepage meter 2 at Station 4.

The word theodolite is mispelled in the original report (as "theotolite" on page 12). A theodolite is a common surveying instrument used in determining horizontal and vertical angles.

In the analysis of the hydrologic data, we determined that the stream floodplain area was the primary area contributing drainage to the surface water (i.e., stream and pond) during storm events. This statement implies that other areas of the watershed than the floodplain were less significant in contributing drainage to surface water during storm events.

The units in Table 2.11 are m^3.

Revisions to Chapter 3: ORGANICS

Table R2. Dates of analyses of organics samples.

Sample Name	Date of analysis
S-4	8/27/90
S-5	8/27-28/90
S-6	8/28/90
S-7	8/28/90
SW-5 (9/3)	10/2/90
SW-9	10/2/90
SW-10	10/3/90
SW-11	10/4/90
LW-1	10/5-7/90
LW-2	10/8/90
SW-6 (9/3)	10/8/90
SW-8 (9/3)	10/9/90
SW-8 (8/2)	10/9/90
SW-12	10/10/90
SW-6 (8/2)	10/10/90
SW-5 (8/2)	10/10/90
S-1	10/11/90
S-2	10/11/90
S-3	10/11-12/90
S-7r	10/12/90
UVAPZ-4	10/15-16/90
UVALP-3	10/16/90
UVAPZ-4s	10/16-17/90
UVALP-3s	10/17/90

The pore size of the filters employed in the preparation of samples for organics analysis were

Whatman no. 1 = 11 μm
Whatman no. 4 = 20-25 μm.

The samples names WW-14 and WW-15 were inappropriately used on page 58 of the final report. Those sample names should be replaced by the names used consistently throughout the rest of the report:

UVAPZ-4 replaces WW-14
UVALP-3 replaces WW-15.

On page 59 of the final report, the PNA's were reported as approximately 10,000 ppm for sample S-5. This statement is incorrect. Rather, TEH is approximately 10,000 ppm for sample S-5 and is so correctly reported in Table 3.3.

Revisions to Chapter 3: METALS

The results of the metals analyses that we report were provided by Mike Lockhart of Havens Laboratory in Charlottesville, Virginia. Mr. Lockhart had been working with Yacov Haimes and Ralph Allen in work on this project before the Department of Environmental Sciences became involved. We have listed in Table 4.3 of our report everything that was made available to us by Mike Lockhart or Yacov Haimes regarding the water samples that we had collected. We do not have information on dates or methods of sample analysis or on sample pretreatment or storage. We never received any information on the analysis of sediment samples that we had collected.

EXECUTIVE SUMMARY

The study of the Cheatham Annex site conducted by members of the Department of Environmental Sciences of the University of Virginia focused on questions regarding site hydrology and contamination of the site by organic compounds and by metals.

The major conclusions to come out of our study of the Cheatham Annex site follow.

1) Any soluble subsurface contamination that is mobilized in the vicinity of the storage tanks, the discarded drums, the cosmoline dump, and so forth will move down gradient in the shallow groundwater and flow toward local streams and/or toward King's Creek and the York River.

2) No major areas of contamination, other than sediments of Hipps Pond, were discovered in our study. There is large uncertainty, however, regarding the magnitude and extent of undiscovered contamination of soils and groundwater. There is also great uncertainty regarding the possible fate and transport of any contamination at the Cheatham Annex site.

3) Further work is required to

   a) characterize the inflow and outflow of contaminated water in Hipps Pond during winter and spring high-flow conditions;

   b) accurately determine the magnitude and extent of metals contamination at the site;

   c) assess the extent of the contamination of soils by organic contaminants and characterize the soil/water partitioning of those organics; and

   d) determine the rates of sediments in Hipps Pond and the biodegradation rates of organic contaminants in the sediments.

The individual chapters of our report on site hydrology, contamination by organic compounds, and contamination by metals can be individually summarized.

The major points for summary from our hydrological study of the Cheatham Annex site follow.

1) The major input of water to Hipps Pond is the base flow of streams. This base flow is derived from the drainage of shallow groundwater that provides seepage inflow to streams.

2) Summer stormflow originates from narrow riparian zones. Spring and winter stormflows may originate from more laterally extensive surface and subsurface source areas. During wet periods, the combination of storm flow and direct precipitation on the lake surface is a significant component of the water budget of Hipps Pond.

3) Groundwater gradients are very low; the sediments at the site are quite permeable. The hydraulic gradients indicate that groundwater flow is generally toward the southeast, toward King's Creek and the York River.

The major points for summary from our study of the organic contamination at the Cheatham Annex site follow.

1) There is not much organic contamination present at Cheatham Annex except in the sediments of Hipps Pond. This contamination may be due to oil spills in 1977 and 1978. It is possible that additional contamination may be trapped by the sediments following high discharge events into the Pond.

The major points for summary from our study of the metals contamination of the Cheatham Annex site follow.

1) Because of deficiencies in the studies to date, the extent and magnitude of metals contamination is unknown.

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I. INTRODUCTION

IA. Overall Question

The Commonwealth of Virginia Emergency Fuel Storage Facility (CVEFSF), herein referred to as the Cheatham Annex site, is a former Navy fuel supply depot currently administered by the Department of Emergency Services of the Commonwealth of Virginia. During its period of operation since its construction in the 1940's, various grades of fuel were stored and distributed at the site. Acquired by the Commonwealth in 1980, operations at the facility were ceased in 1982, at which time considerations were given to discerning the nature and extent of contamination.

A preliminary site investigation was conducted by the Department of Waste Management (DWM) in December, 1986. A private consulting firm, Engineering Sciences Incorporated (ESI), was contracted by DWM to further assess the status of contamination at the site and draft a set of potential remediation strategies. In June 1989, ESI submitted a preliminary report (ESI, 1989) of their findings. Their report left several unresolved questions concerning the potential for contaminants to move throughout the site.

In April of 1990, the Department of Environmental Sciences at The University of Virginia was contracted to continue research on the site. Although the potential of contaminant migration cannot be completely characterized in even the most extensive investigation, the purpose of our research at Cheatham Annex was to evaluate the hydrological factors which may be important in contamination transport. Furthermore, we attempted to provide a preliminary characterization of organic and heavy metal contamination in areas believed to be sensitive or indicative of the general status of the site as a whole.

Although the likelihood of off-site transport cannot be inferred from our assessment, general conclusions can be drawn about the current state of contamination in hydrologically-significant areas of the site. Our overall research framework at the site was centered around the following objectives:

1) assess groundwater-stream interactions on the North Branch Hipps Creek;

2) characterize the hydrology of Hipps Pond;

3) assess organic contamination of Hipps Pond and on the southeast margin of the site;

4) evaluate heavy-metal contamination in surface waters and groundwater in an area along the North Branch Hipps Creek.

Our research design was to first characterize the hydrology of the site and integrate the important hydrologic factors into the chemical framework established from organic and heavy metal analyses.

IB. General Site Description

Cheatham Annex is located in York County, Virginia, approximately two miles from the York River. The 435 acre site (Figure 1.1) is bounded by Virginia State Highway on the northwest and the Colonial Parkway on the northeast. To the south and southeast, King's Creek and a contributing tributary form the site boundaries.

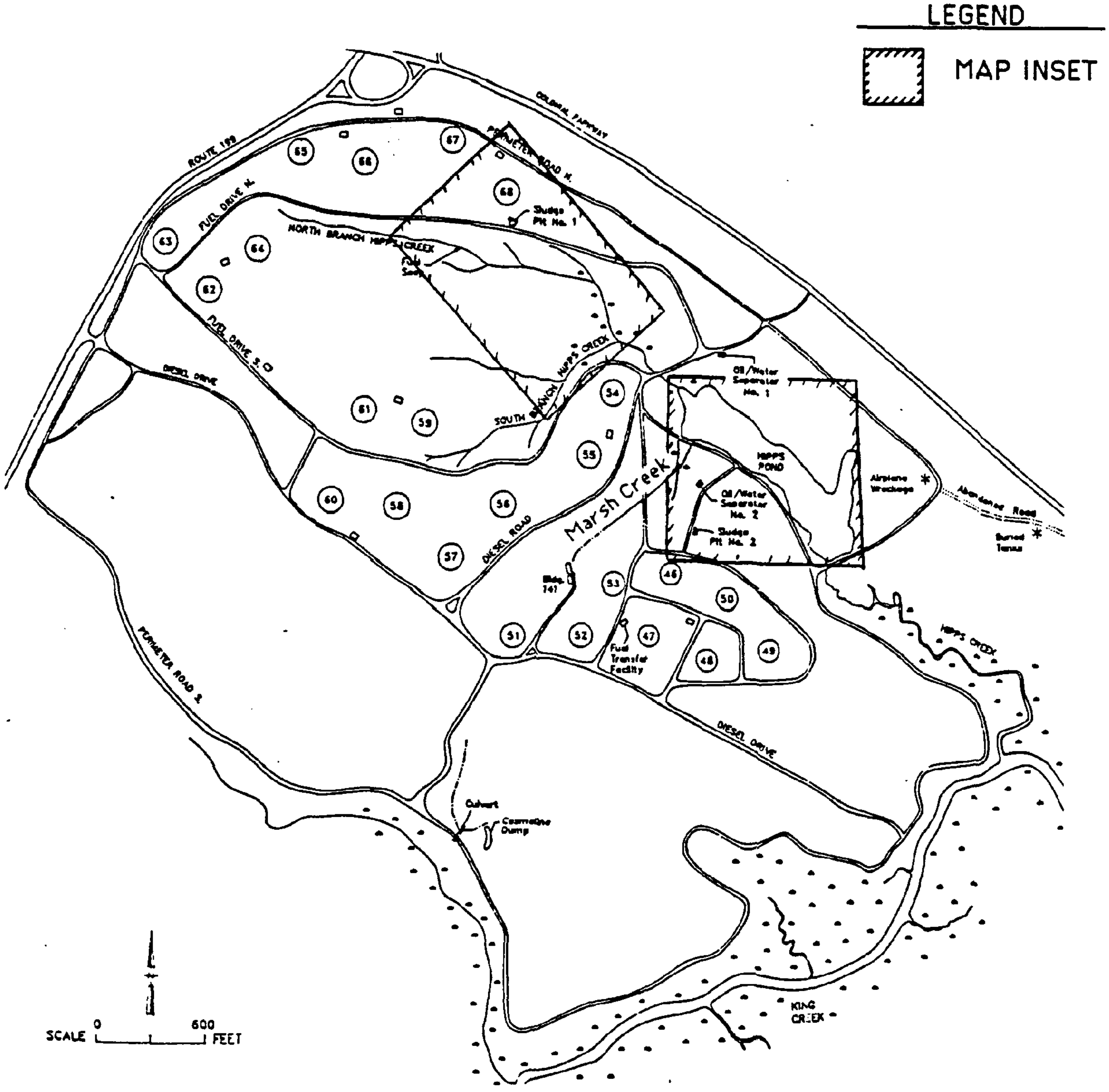
The Cheatham Annex site has a healthy flora and fauna distribution. Clear-cut areas are overgrown with grasses and shrubs while most of the site is forested with mixed pine and hardwood stands. These are populated by various woodland animals and birds. A number of small streams and a pond are inhabited by both fish and other aquatic species.

The site lies within the Coastal Plain physiographic province, typified by disconformable sequences of alluvial and transgressive-regressive marine sediments. In the higher elevations of the site, relatively flat grasslands grade into several entrenched valleys supporting hardwood stands of trees. The site is well drained by a network of incised perennial and ephemeral streams which flow into an artificial pond near the eastern boundary. Hipps Pond lies at the lowest elevation of the site, nearly 80 feet below the headwater regions of the upland contributing areas.

Various fuel storage and distribution structures are distributed around the site, the most conspicuous of which are 23 2.5 million gallon storage tanks. Eighteen tanks are concrete and completely below grade. The remaining five are of steel construction and are partially buried. The fuels distribution network for these tanks also includes valve boxes, oil/water separators, and pipelines located throughout the site.

Figure 1.1.

CHEATHAM ANNEX
SITE MAP



(Taken from: ESI, 1989)

CHEATHAM ANNEX PROJECT
Department of Environmental Sciences
University of Virginia
December 1, 1990

II. HYDROLOGY

II A. Introduction

The strategy of our hydrological research at the Cheatham Annex site was to identify the major factors which may play a role in the potential for contaminant migration within the site. We concentrated our efforts on groundwater-stream interactions in the North Branch Hipps Creek and the water fluxes into and out of Hipps Pond. We sought to first understand the dynamics of groundwater inflows to the North Branch because of the dominance of surface water drainage at the site. We examined groundwater input to the North Branch over three major periods: during storm events, over extended base-flow periods, and over monthly intervals. The overall purpose of the North Branch research was to develop relationships to estimate the surface water and groundwater contributions to Hipps Pond.

The motivation for the design of our field experimentation for an understanding of the hydrology of Hipps Pond stems from the expected salient control of the Pond over nearly all surface-derived water entering the site. Situated at the lowest point at Cheatham Annex, Hipps Pond drains nearly 75% of the site's surface area and thereby serves as the final reservoir for most of the water before leaving the site. Our primary objective was to identify the sources of water entering the North Branch under different conditions and to extend those interpretations to appraise the relative importance of all inputs and outputs to Hipps Pond.

IIB. Site Description

Hipps Pond

Hipps Pond is located near the central eastern margin of the site, and is bounded by an artificial berm and dam on its inflow and outflow ends, respectively. Three streams contribute surface water inflows to the pond: the North and South branches of Hipps creek, and a "marsh" creek directly entering Hipps Pond (Figure 2.1). Surface water leaves the pond through a standpipe which empties into a discharge stream. Direct groundwater inflows to the pond are derived from two major drainage areas to the south and north of the pond. On the north side, the perimeter road approximates the surface water drainage divide, whereas on the south side, the divide extends up to Diesel Drive (Figure 2.1). Both drainage areas are comprised of relatively gentle slopes covered with stands of hardwood trees.

In order to investigate direct groundwater inflows to Hipps Pond, a region of the southern drainage area near the pond was selected for study (Figure 2.2). The south side was chosen because it drains a considerably larger area than the north side, and it includes several storage tanks within its boundaries.

North Branch Hipps Creek

The North Branch Hipps Creek (herein referred to as the North Branch) drains the largest area of the site, and is the longest tributary of Hipps Creek (Figure 2.1). The upper half of the stream is characterized by steep sideslopes, a relatively narrow floodplain , and an incised channel (Figure 2.3). The sideslopes directly intersect the banks of the channel in certain areas, whereas a moderate floodplain or terrace is present further downgradient. The channel and bank material consist of sands, silty sands, and organic debris.

In the lower reaches, the North Branch is moderately entrenched into a floodplain which is considerably wider than corresponding areas in the upper reaches. Most of the floodplain in this area is marshy, and towards the confluence with the South Branch, the creek bifurcates into several channels. The channel material and the deposits along the banks and floodplain become siltier in the downstream direction. The South Branch and the marsh creek (Figure 2.3) share similar attributes with the North Branch along their lengths. For our experimentation, we selected a region of the North Branch which was representative of the upper reaches of all creeks at the site.

IIC. Field Methods

North Branch

Instrumentation

The design of our research on the North Branch was to assess the components of inflow to the stream and determine the relative magnitude of each. We employed three methods to provide estimates representative of total inflow, vertical inflow, and lateral inflow to the creek. Because the interaction between surface and subsurface water was of interest, we concentrated our field efforts on the near-stream areas of North Branch.

Base-flow and storm discharges were monitored with a Parshall flume (1 inch throat) equipped with a continuously-recording analog water-level recorder. The flume was installed near VP-14 (Figure 2.3), and was situated upstream of a minor rill in an area with a moderate floodplain and fairly small (0.5 m) banks. The flume was secured with reinforcing bar and grouted in place. An earthen dam was constructed upstream of the flume to create a small stilling pond.

In order to assess the vertical and lateral groundwater inflows to the North Branch, fifteen 1.2 and 2.5 cm hand-augered observation wells were installed (Figure 2.3). Included in this network were three nests of two piezometers installed directly in the stream to measure vertical gradients into the stream bed. Wells along the banks and the sideslopes provided water levels for lateral gradients into the stream.

The installation of all wells and piezometers began with a 2.5 to 5 cm boring to the desired depth of the instrument. After the instrument was placed in the hole, well sorted coarse sand was poured around the screened interval of the casing. The bore hole was then filled with a bentonite grout to seal the casing from the top of the screened interval to the ground surface.

Nearly all wells and piezometers were equipped with an inner acrylic tube filled with cork at the base to measure high water levels. The cork would rise with water levels during a storm, and adhere to the side of the acrylic after water levels receded. During a site visit, two water levels were obtained: a current water-level and a high-water level corresponding to the most recent storm. So equipped, the water levels from the wells and tensiometers were used to examine water-level rises during storm events, and recovery times following.

The dominant sediment type encountered in the borings for hillslope and floodplain wells was a silty sand which included occasional interbeds of clayey silts and shells (Table 2.1). The water bearing unit for the site is the Yorktown formation (ESI, 1989), the top of which was exposed on the sideslopes upstream of the flume. Within the stream channel however, recently deposited well sorted sands were interbedded with prominent leaf and organic layers.

In addition to groundwater inflow estimates derived from lateral and vertical water-level gradients, vertical seepage into the stream channel bottom was measured directly with seepage meters. These instruments are identical in design to those used in a study at Lake Anna, Virginia (McIntyre, 1988). The meters are essentially a 30 cm section of 20 cm (ID) PVC pipe with a funnel affixed to the opening at one end of the pipe. They were installed to a depth of 30 to 35 cm by first excavating a hole, and driving the pipe to the depth at which the funnel top was equal in elevation with the stream channel bottom. All air was purged from the meters before a condom was attached to the end of the funnel. Over the course of a sample period, seepage water would enter the pipe and collect in the condom. The water volumes collected from these meters provided a direct estimate of vertical inflows in several locations along the North Branch, from which inflow rates per unit stream length were computed.

In-stream Dilution Gaging

A final assessment of groundwater inflows was made by conducting an in-stream dilution gaging experiment. This field method was used to derive total inflow estimates for the North Branch along our study region. The principle of the experiment is based on mass balance. The injection inflow rate and concentration of a conservative tracer are related to observed downstream concentrations diluted by groundwater inflows.

An experiment was conducted on 16 May under base-flow conditions. A potassium bromide solution was introduced into the stream at rate of 3.85 mL/s from a location in the upper reaches of the North Branch (Figure 2.3). In-stream tracer concentrations were monitored at five sample stations positioned downstream of the injection point (Figure 2.3). The experiment continued until tracer concentrations at all sample locations stabilized over time. The observed concentrations were related to the tracer inflow rate and concentration to estimate the discharge at each sample location. Groundwater inflow rates between stations were computed by simply subtracting the calculated discharge at a station from the discharge at the next downstream station.

Water Conductivity and pH

We completed our investigation of groundwater inflows to the North Branch by monitoring pH and conductivity at several locations along the length of the stream. We believed that significant inflows of "old" resident water might be represented by variability in either chemical parameter along a stretch of the creek. Measurements were taken from several riparian wells and also at ten in-stream sample locations (Figure 2.3; Table 2.2). No observable differences in these measurements were detected along the length of the North Branch or between surface water and groundwater.

Hipps Pond

Instrumentation

The primary objective for our research on Hipps Pond was to examine all inflow and outflow water components. Surface water outflows, groundwater inflows, and pond level stage were monitored over the course of the study period.

Surface water discharges in the outfall stream were monitored with a Parshall flume (6 inch throat) installed directly below the standpipe from Hipps Pond (Figure 2.2). Water levels were continuously monitored with an analog recorder. The flume was secured with reinforcing bar and grouted in place.

Changes in pond storage were determined from an in-pond meter staff and a water-level recorder. The recorder monitored water-levels continuously, which were related to observed heights from the meter staff. In addition, rainfall was continuously recorded by a weighing-bucket raingauge (Table 2.3).

A set of hand-augered wells (Table 2.1) was installed along a transect perpendicular to Hipps Pond (Figure 2.2). Water levels were continuously recorded in one of the wells, UVAPZ-1. In addition, two nests of piezometers were installed along the margin of the pond. Other wells were situated near existing ESI wells to establish directions of groundwater flow. In all wells, a sand pack was positioned around the screened interval and a grout slurry was poured above the sand to the soil surface. The slurry was used to bind the well casing to the soil to inhibit rainwater from traveling down the casing into the subsurface. In piezometers, the grout slurry extended from the top of the screened interval to the soil surface.

A nest of tensiometers (Table 2.4) was installed near piezometer nest UVALP1/LP2 and tied into the transect of wells upslope (Figure 2.2). In addition to monitoring soil moisture, one of the four tensiometers recorded pond level and served as a reference for removing temperature beases in the digital records from the other tensiometers (Hoelscher et al., in revision). All tensiometers were equipped with pressure transducers. The millivolt output from the transducers was recorded by a data logger which also collected ambient air temperature at ten minute intervals. This nest of instruments was located at the downslope end of a major draw. We suspected that the draw might be a major groundwater flowpath during storm events.

During borings for well installations, soil types were visually identified and recorded in field logs (Table 2.1). The predominant sediment types on the contributing slopes of Hipps Pond were medium grained silty sands to very clean homogeneous sands. Interbeds of clay and shell material were encountered in several well borings. A moderate to strong petroleum odor was present in nearly all well sediments.

Pond Volume/Area Estimates

The bathymetry of Hipps Pond was determined from a total of twelve transects across the Pond. Transects were taken across the narrow width of the pond from a base line along the southern bank at 30-m intervals. Water depth measurements were taken along each transect at 7.5-m intervals. The measurement sites along each transect were more closely spaced than transect intervals because of the greater expected variability across the bottom. Three additional transects were taken across the finger-like cove on the northeastern side of the lake. These data were used to construct a bathymetric map of the pond, from which the pond area and volume were determined.

Hydraulic Conductivity Estimates

To complete our evaluation of groundwater inflow to the North Branch and Hipps Pond, two experiments were conducted to determine saturated hydraulic conductivities of hillslope soils. Slug tests were conducted on several occasions on wells NW-4, NW-3, NW-2 and NW-12 on the North Branch, and PZ-1 and PZ-4 near Hipps Pond (Figures 2.2 Figure 2.3). A PVC section with an attached manometer was fit directly onto the top of the well casings. Water was poured into the attached PVC until the water level in the manometer would reach a designated starting level. Water input was discontinued, and head levels in the manometer would be recorded at successive time intervals.

Direct measurements of hydraulic conductivity were not obtainable with this method. Two experimental difficulties disallowed completion of the experiments: either the input flow rate was inadequate to reach a constant level in the manometer, or the rate of head drop in the manometer was too rapid for water level observation. These difficulties were indicative of fairly high saturated hydraulic conductivities.

A second approach was undertaken in which potassium bromide was introduced into a well and monitored in a down-gradient well. A concentrated bromide solution was poured into well NW-3 which was installed on a north facing hillslope. Concentrations were monitored in well NW-12, approximately 4 m downslope of NW-3, for two days. During that interval, bromide concentrations in NW-12 did not significantly change. A similar experiment was conducted using UVA wells PZ-1 and PZ-2 on the south side of Hipps Pond. Bromide was not recovered in the down-gradient well (PZ-1), which is approximately 25 m from PZ-2. Both tracer tests suggested that either low gradients, low hydraulic conductivities (inconsistent with slug test results), or heterogeneous soils characterize the regions between test wells.

Although a direct estimate of hydraulic conductivity (K) was not obtained, we estimated a value based on published values (Freeze and Cherry, 1979) for similar deposits and direct observations of rapid drainage in the slug tests. For the hillslope sediments, we estimated a range of possible K values from 10^{-2} to 10^{-3} cm/s, which represents the upper end of hydraulic conductivities.

Instrument and Topographical Survey

The locations and elevations of all UVA instruments were determined with a theotolite (Table 2.6). In addition, a topographical survey (Figure 2.2; Figure 2.3) was completed for the entire length of the North Branch (including local drainage areas), the mouth of the South Branch, and the "local" drainage area to the south of Hipps Pond. Elevation control points were established from several ESI wells adjacent to the North Branch and near Hipps Pond.

IID. Analysis

North Branch

Base Flow: Inflow Sources

Groundwater inflows to the North Branch were subdivided into three groups in our analysis: total, vertical and lateral. The control for assessing the relative proportion of each was established from the results of the dilution experiment. Direct measurements of vertical seepage were obtained from the seepage meters, and water levels from wells and piezometers provided calculated estimates of both vertical and lateral inflow rates.

The results from the dilution experiment were used to derive an estimate of total groundwater inflow per unit stream length. Discharge gain over a length of stream was determined by simply subtracting the discharge at an upstream station from the successive downstream station. This gain was then expressed as an inflow rate per unit meter of stream by dividing the difference by the distance between stations.

Total inflow was then partitioned into lateral and vertical components. Lateral inflow was not directly measured, but estimated with Darcy's Law. Darcy's Law can be expressed in a finite difference formulation:

$$Q = KA\,[h2\text{-}h1/L2\text{-}L1] \qquad (1)$$

where

Q = volume discharge per time (L^3/T),
K = saturated hydraulic conductivity (L^2/T),
A = cross-sectional area (L^2),
$h1\text{-}h2$ = head difference between two points,
$L1\text{-}L2$ = distance between points.

This equation relates the volume outflow across a unit area to the groundwater gradient and the saturated hydraulic conductivity.

All water levels were first expressed in terms of absolute elevation. For adjacent wells and wells near the creek, head differences were divided by the corresponding distance between points to estimate the gradient. The area was estimated by considering a unit meter length along the stream, and estimating the intersection of the water table with the stream to be 1 m. The 1 m width roughly corresponded to the channel width.

Two monitoring intervals were selected for gradient computations, one in the early part of the field season, and one in the late. These two intervals were also selected because water levels collected during those intervals were known to be reliable. Experimental problems arose with the acrylic tubes in the small diameter (1.25 cm) wells and piezometers. The emplacement of the tubing into the wells displaced considerable water, resulting in spuriously high "current" and "high" water levels. Before the problem was corrected, "current" water levels were completely unreliable. This was clearly demonstrated by the high variability of water level differences among nested piezometers over several monitoring intervals (Table 2.5).

Because tests for K were not conclusive, a range of values from 10^{-2} to 10^{-3} cm/s was used as described in section IIC of this report. Lateral inflows to the creek were then calculated with these variables for two monitoring intervals.

Vertical seepage estimates were calculated using Darcy's Law as specified above. Three piezometer nests along the North branch provided potentiometric head readings from which gradients were computed. The largest unknown parameter in this application of Darcy's law was the hydraulic conductivity. Due to the presence of continuous layers of highly restrictive leaves and organic matter within the channel bottom sands, we reduced the range of possible conductivities by a factor of ten from the lateral inflow calculations. Two endpoints of conductivity, 10^{-3} and 10^{-4} cm/s, were used to calculate the vertical inflow rates.

These estimates were compared with direct measurements of vertical seepage from the seepage meters. Over certain intervals during the field season, a meter was installed near each piezometer nest. The measured inflow rates were calculated for a unit area having dimensions of 1 m by 1 m, the same flux area used for the gradient-based values. Based on the discrepancies between the estimated and measured vertical seepage rates, the applicability of the estimated hydraulic conductivities was quantified.

Base Flow: Longitudinal Discharge Rates

The proportion of lateral and vertical inflow to total inflow was extended to characterize groundwater inflows along the entire length of the North Branch, South Branch, and the marsh creek. Based on the results from the dilution experiments, we derived a relationship between the inflow rate and the corresponding contributing area along a reach of interest. The areas were estimated by extending perpendicular lines away from each creek segment considered in the dilution experiment. This inflow per unit area relationship was "calibrated" to consider spatial and temporal changes in the factors affecting inflow rates.

Spatial variability was included in the inflow relationships through groundwater gradients and hydraulic conductivity. An "effective" reference groundwater gradient to the North Branch in the area of the dilution experiment provided an inflow estimate. The dilution-based estimate and gradient-based estimate were equated by using a value for the hydraulic conductivity which gave the same inflow rate as the dilution-based estimate.

Over other drainage areas, regions were delineated in which gradients different from the reference gradient (Table 2.6; Table 2.6a). The ratio of the observed gradient in another area and the reference gradient was used to adjust the inflow rate for the area of interest. In areas in which data were not available, the topography was used to estimate the gradient. This relationship was also used to estimate groundwater inflows in regions where hydraulic conductivities differed from values used in the North Branch study area.

Besides gradient and hydraulic conductivity, base-flow through the North Branch flume was included as a factor to adjust inflows for temporal changes. Base-flow at the location of the North Branch flume was approximated for the dilution experiment. Total inflows over base-flow periods were then scaled depending upon the observed discharges through the North Branch flume. The combination of all these factors was used to estimate total surface water contributions to Hipps Pond over base-flow periods.

Storm Flow: Source Areas

The other important component of surface water/groundwater interactions is storm runoff. Significant volumes of water can be moved through a catchment during a storm. We sought to delineate the most active areas near the stream during storm events in an attempt to estimate total storm volumes into Hipps Pond.

To evaluate the source of storm-response discharges in the stream, high-water marks from wells were segregated by proximity to the stream. High-water marks also provided information about the potential for stream bank storage to occur during a storm. We believe that very steep gradients immediately adjacent to the stream may temporarily "reverse" the gradient upslope and change stream bank storage. After passage of the hydrograph peak, extended recession limbs might result from this considerable storage. Storm hydrographs were the fundamental unit of observation for our analysis of storm flows in the North Branch. Storm volumes through the North Branch flume were determined by integrating the area under the hydrographs.

During the course of the summer, several storm responses were not recorded due to the timing of intervals for instrument operation. Typically, the only data available were pre-storm discharge, peak discharge, and discharge during a field visit. Based on the unit hydrograph concept, we devised a method to estimate the storm volumes corresponding to the observed peak discharges. Our main assumption was that the relationship between the peak discharge and the total storm volume remained constant. By doing so, we did not restrict ourselves to the assumption that storm "yield" or excess rain at the site was constant over all storms.

A ten minute unit hydrograph was created from a hydrograph following an "average" rainfall. The storm volume was calculated by removing baseflow and scaling the hydrograph with the ratio of the observed rainfall to a 1 cm rainfall. Storm volumes from missing hydrographs were estimated by multiplying the unit hydrograph by an appropriate rainfall which yielded the observed peak discharge. This method did not account for differences in observed rainfall values; it simply related observed peak discharges to corresponding storm volumes based on a constant relationship between the two.

Storm Flow: Total Storm Volumes

It is generally acknowledged that groundwater does not play a significant role during storm events in upland forested catchments (Cherry, 1974; Kolla, 1987). Based on the high-level marks in the wells, we determined the active areas contributing to storm flow. Our overall interest was to determine the total storm volumes from all creeks into Hipps Pond.

The floodplain area was selected as the main contributing area during storms. The observed storm volumes through the North Branch flume were expressed as a flux across the upstream floodplain area of the flume. Floodplain areas were delineated on the North Branch, the South Branch (Figure 2.4), and the marsh creek. For each storm, the flux derived from the North Branch flume data was applied to all downstream floodplain areas on the North Branch, South Branch, and the marsh creek. The main assumption of this methodology was that storm yield in the upper reaches of the North Branch was representative of the entire length of each creek.

Hipps Pond

Our analysis of the hydrology of Hipps Pond was subdivided into base-flow and storm-related periods. The relative importance of all components was appraised under these different conditions. The final analysis of Hipps Pond was extended to a monthly time scale to consider the changes in the proportions of each component over seasonal periods.

Area and Volume Calculations

Values for pond surface area and total water volume were instrumental in the water budget calculations. Surface area was calculated graphically using a scaled map of the pond. This plan was gridded into 1 m^2 sections. The total area of the pond was calculated by summing all sections included within the pond boundaries. The total area was calculated to be approximately 25,400 m^2.

In order to calculate the volume of Hipps Pond, a depth profile from our field survey was created. The original data were horizontally adjusted to align all transects along a common grid axis. This information was used to create a bathymetric map (Figure 2.5).

A volume integration routine was also used to calculate the pond volume. We were not able to force the program to recognize the boundary points of the pond, which led to initial over-estimations of the pond volume. This problem was circumvented by calculating the volumes corresponding to each contoured area of depth. An approximate lake volume was derived by summing these contoured areas. This method provided an estimate of 45,000 m^3, which roughly agreed with the volume corresponding to an average pond depth of 1.5 m.

Base Flow

The two major inputs to Hipps Pond during base-flow (or inter-storm) conditions were surface water inflow and direct groundwater inflow. The inflow relationship among groundwater inflow rates, hydraulic conductivity, and groundwater gradients was used to estimate the total surface water inflow to Hipps Pond. This relationship was extended to estimate direct groundwater inflows.

For direct groundwater inflows, two major variables of the relationship differed from those used in surface water inflow calculations on the North Branch: the cross-sectional area across which groundwater entered the pond, and the hydraulic conductivities. The cross-sectional area (or flux plane) was estimated from our pond bathymetry analyses. A conservative value of 1.5 meters was chosen as the width (or depth) of the plane. The drainage area on the south side was subdivided into two regions based on the differences between observed gradients. The straight-line distances along the shore of each subdivided region provided the length of the flux plane for each drainage area.

Although the hillslope sediment in each subregion was nearly identical to hillslope sediments on the North Branch, the pond bottom sediments ultimately controlled inflow rates to the pond. The predominant lake sediment type was a sandy clay, overlain by an organic rich silty clay. Based on published figures (Freeze and Cherry, 1979) we estimated the hydraulic conductivity of the material to be 10^{-4} cm/s. The total groundwater inflows were computed with these variables for the north and south sides of the pond.

The output components roughly correspond to the sum of the surface water and groundwater inflows to the pond. Perhaps the most important was the pond discharge through the outfall stream. Discharge data from the outfall flume were integrated over base-flow periods to estimate total base-flow output volumes.

During the summer, the other important output component was evaporation from the lake surface. We selected the Hamon method (Hamon, 1961) for estimating potential evapo-transpiration (PET) because the only input requirements were latitude and daily average temperature. It has been shown to yield comparable values with those from more detailed and sophisticated methods (Hamon, 1961). We made a preliminary test of this observation by comparing estimates from the Hamon method with those from the Priestly-Taylor method. The data came from a fresh-water marsh at approximately the same latitude as the Cheatham Annex site. We could not identify a significant bias in the Hamon method estimates. Estimates for the pond PET were calculated from daily averages of temperature readings collected by the data logger.

Seepage through the dam at the outflow end was also estimated. Although no data were directly available to make the calculations, gradients were estimated, and the hydraulic conductivity for the pond sediments was used.

Pond storage changes were also computed for the base-flow intervals. Daily pond level for each interval were computed by subtracting the end pond level from the starting level, and dividing by the time interval. All components of the base-flow intervals were expressed in terms of flux across the pond area per day.

Storm Fluxes

Our primary objective for examining storm responses in Hipps Pond was to compare the relative contributions of the two major inputs: direct rainfall on the pond aquifer surface and surface storm flows. We were also interested in the relative changes of each input component across different storms, and possible groundwater bulging at the lake margin during storms.

In order to estimate the components of lake responses during a storm event, we established a time reference with the lake level hydrograph. Clearly, the total duration of surface water runoff can not be accurately estimated from discharge data in the headwater regions on the North Branch. We did however, have good temporal control on rainfall duration, lake level responses, and lake discharge.

Our analysis of storm events focused on two intervals represented in nearly all lake hydrographs. The first interval comprised the initial lake level response to nearly constant peak levels (Figure 2.6). We assumed that all rain fell during that interval, and surface runoff was initiated into the creeks. The second interval was defined by the steady-state pond levels following nearly all storms. With no storage change, inflow rates equal outflow rates. During these intervals, PET was assumed to be zero. Hence, the only active components were surface water input, lake discharge and storage changes. Because the latter two components could be estimated with some certainty, the dependability of the calculated surface water inputs could be assessed.

We also sought to evaluate the buildup of groundwater gradients at the pond margin from the tensiometer records of soil water pressure. Although we had hoped to establish a control for removing temperature biases in the digital output from the transducers, each transducer behaved differently in response to thermal and solar loading. These thermal and solar factors were found to exert more control on the output than actual changes in soil water/lake level pressure changes (Figure 2.7). The large excursions in the output followed quite closely the ambient air temperature fluctuations (Figure 2.8). The variability of transducer output with respect to environmental factors was too great for accurate reconstructions of soil pressure gradients to be made.

Monthly Water Budget

Our overall assessment of the hydrology of Hipps Pond focused on monthly water budget calculations. Monthly averages were computed for surface water base flow, groundwater inflow, dam seepage, PET, and storage changes. Total surface water storm volumes were also calculated. Total pond discharge volumes were computed by integrating under the monthly time-series discharge records from the outfall flume.

A crucial aspect of the monthly water budget was the error associated with each component. In part, the base-flow and storm event analyses provided a starting point for assessing the magnitude of each error component because of the control on certain components. Although straightforward methodology does not exist for estimating errors in each, we followed the error analysis in Winter (1981) to approximate probable uncertainties.

Clearly, our surface water estimates represent one of the highest uncertainties on the monthly time-scale. The major source of error for surface inflow estimates is the assumed constancy of inflow rates over space. Although we accounted for gradient changes, we do not have any direct way of verifying these estimates other than comparison with other nearby catchments. As a crude approximation to an error estimate, we calculated discharge per unit area from several gaged catchments of various sizes on the coastal plain of Virginia. The variability of values for several months was used as an indication of the likely uncertainty in our inflow estimates.

Residence Times

Our final characterization of the role of Hipps Pond in mediating inputs and outputs from the site was established by calculating mean water residence times. Over the course of the three month study period, total inputs were assumed to equal total outputs with no net change in lake storage. The mean residence time (T) of a parcel of water can be computed with

$$T = V/R \tag{2}$$

where

V = pond volume,
R = steady inflow/outflow rate.

IIE. Results

North Branch

Base flow

The results from the dilution experiments indicate that groundwater inflows to the North Branch are fairly constant along the study reach (Table 2.7). Expressed in terms of inflow per unit drainage area, all inflow estimates are nearly equal, ranging from 1.9×10^{-5} to 2.2×10^{-5} L/m^{2}s.

Vertical seepage measurements were variable along the study reach but fairly constant at each location (Table 2.8). Observed seepage rates did not appear to be related to observed gradients in nearby piezometer nests (Table 2.9). It is likely that the restrictive leaf layers are laterally discontinuous resulting in varying vertical hydraulic conductivities of the channel material along the North Branch.

Groundwater gradients generally increased with proximity to the stream (Table 2.9). Lateral gradients do not significantly vary however, but are generally much lower than vertical gradients in the creek channel. Based on the observed gradients, the "effective" lateral gradient into the North Branch in the study area is 0.042, which represents an average of all observed gradients.

Lateral inflows to the creek comprise the largest percentage of total groundwater inflows to the creek (Table 2.10). The highest measured vertical seepage rate (5.7×10^{-3} cm/s) at nest UVANW-6/NW-7 is lower than the total measured seepage by over a factor of one hundred. Based on the dominance of lateral inflows to the creek, a hydraulic conductivity of 1.5×10^{-2} cm/s corresponds to an observed gradient of 0.042 and a flume discharge of 4.0 L/s. These variables are directly related to the inflow per unit drainage area (Table 2.7) determined from the dilution experiment.

The importance of lateral inflows during base-flow conditions confirms field observations of considerable seepage from bank faces and sideslope bases. On several occasions, test pits excavated into the banks quickly filled with water. These results indicate that a relatively small vertical section of the water bearing formation (Yorktown) intersects the North Branch.

The considerable storage of the Yorktown is further demonstrated by fairly constant base-flow discharges through the North Branch flume over the course of the summer. Furthermore, groundwater gradients did not significantly decrease among most wells (Table 2.9). Only in early October, following an extended period (1.5 months) of rainless weather, did water cease to flow through the flume. At that time however, surface water flow was present approximately 100 m from the flume.

Storm Flow

Storm hydrographs through the North Branch flume indicate that the creek responds very rapidly to storm events. Typically, peak discharges occur approximately 30 to 60 minutes following the onset of rain (Figure 2.9). Most storms during the study period were however, very severe and of high intensity (Table 2.3). The descending limbs of the North Branch hydrographs represent fairly rapid returns to near-base-flow discharges, which suggests that bank storage is not significant. In nearly all hydrographs, base flow conditions were established approximately 12 to 18 hours after the passage of the peak discharge.

The major areas of storm water contributions appear to be limited to the near-stream, or riparian areas. Over several storms, water level responses were high in all near-stream wells (Figure 2.10). The water levels of the deeper wells far from the North Branch were largely unaffected by all storms over the summer field season. Considering the steep sideslopes on all creeks at the site, it is likely that storm responses are largely limited to the floodplain areas.

Storm volumes expressed as fluxes across the floodplain area above the North Branch suggest that storm yield was not highly variable (Figure 2.11). The sediments of hillslopes bases and the floodplain drain rapidly and most likely return to pre-storm conditions within two days.

Hipps Pond

Monthly Water Budget

Over the course of the study period, the primary input to Hipps Pond is surface water under base-flow conditions (Table 2.11). Direct groundwater inflows are negligible compared to monthly surface water inputs. During the wet months of July and August, total storm water volumes (surface and direct rainfall) were nearly as high as base-flow inputs. During the drier month of September however, base-flow is the predominant inflow component to the pond.

The outputs from the pond were nearly evenly distributed between PET and pond discharge. The importance of PET lessens during September, particularly during distinct base-flow periods (Table 2.12), but still represents a significant proportion of the outflow from the pond.

During individual storms, direct rainwater inputs are slightly greater than surface water runoff (Table 2.13). The importance of surface runoff and direct rainfall over groundwater inputs during storms is well demonstrated by very minor responses in well PZ-1 during very intense rainstorms (Figure 2.12).

Although our results demonstrate the importance of base-flow inputs, and PET and lake discharge outputs, consideration of the errors involved with each estimate suggests that PET and total surface water inputs contained the largest degrees of uncertainty (Table 2.15). Calculations of surface water discharges from several gaged stations yielded a mean of 6.9×10^{-5} L/m^2 s, with an average standard deviation of 3.2×10^{-5} L/m^2 s. These results suggest that the variability of the inflow rates may be 100 %.

Our own results suggest that the uncertainty may be biased in the negative direction, i.e. surface water inflows — including storm runoff — are underestimated (Tables 2.12 and 2.13). It is likely that the negative residuals for inter-storm periods (Table 2.12) results from a combination of overestimating PET and underestimating surface water inflows.

It is also quite probable that both groundwater inflows and dam seepage are underestimated. Although their contributions to the overall budget remains minimal, it is important to consider the offsetting effects of each estimate. Both flux rates are fairly constant through the seasons because each component intersects a fairly wide flux area. Furthermore, the gradients driving each component would not significantly change over time. Hence, although each may be underestimated, their combined importance would probably be negligible. Upon consideration of all errors, we believe that the relative proportions of each component to the overall budget would not significantly change.

Water Residence Times

Based on average total outflows from the pond over the study period, the average residence time of water in the pond is approximately 7 months. During the fall and winter months as rainfall and PET drop, net input and output rates would drop, resulting in higher net residence times. During the spring however, as recharge occurs and inflows increase, the net residence time would probably increase. Considering the total volume of water moved through the pond during the summer months, it is likely that 7 months represents the average residence time on a yearly basis.

IIF. Discussion

Because hydrology is the driving force behind contaminant migration, it is necessary to consider not only the relative proportions of water entering Hipps Pond, but the source and the chemistry of the water. Base-flow is the largest input component to Hipps Pond and represents water from approximately 75% of the site. In a pure hydrological interpretation, the majority of dissolved and suspended contaminants would enter the pond under base-flow conditions. Furthermore, because the hazardous material storage drums identified by ESI are located within the largest drainage areas, potentially contaminated groundwater from these areas would not be considerably diluted with relatively "clean" groundwater in the creeks.

The migration of contaminants may become slightly higher in spring months as gradients increase and inflow rates increase accordingly. Furthermore, increased contaminant inputs to the pond during spring months would not proportionally increase the pond contaminant concentration due to direct rainfall onto the pond surface and perhaps cleaner storm flow water. Upon reaching Hipps Pond, pond water residence times are long enough to allow for possible physical and chemical processes to occur which may reduce contaminant concentrations at the pond outflow.

If chemical factors were associated with the ability of contaminants to move, contaminants may tend to accumulate near or in the floodplain sediments. Our results indicate that the bulk of storm water is derived from the floodplain areas, suggesting that "spike" inputs of contaminants would be associated with storm events. Considerable water is moved through the pond during these events, which would represent the greatest potential for dissolved and suspended contaminants to move through the pond over the shortest time interval. Although storm volumes on a monthly basis are hydrologically less important than base-flow inputs, they may represent the most important chemical pathway for contaminant migration to the pond.

In summary, our hydrological research on the North Branch Hipps Creek and Hipps Pond suggests the overall control of base-flow on the hydrology of Hipps Pond. Highly conductive soils and very low groundwater gradients sustain the creeks through extended dry periods although significant recharge does not occur in the summer months. Although of slightly lesser importance on a monthly basis, surface storm responses are extremely rapid and mobilize considerable volumes of near-stream riparian groundwater. Direct groundwater contribution into the pond is relatively insignificant mainly due to the low conductivities of the lake bottom sediments. During the summer months, outputs are evenly distributed between evaporation and pond discharge. On a yearly basis, surface base-flow and lake discharge are the largest overall components of the pond hydrology.

IIG. Summary

The major points for summary from our hydrological study of the Cheatham Annex site follow.

1) The major input of water to Hipps Pond is the base flow of streams. This base flow is derived from the drainage of shallow groundwater that provides seepage inflow to streams.
2) Summer stormflow originates from narrow riparian zones. Spring and winter stormflows may originate from more laterally extensive surface and subsurface source areas. During wet periods, the combination of storm flow and direct precipitation on the lake surface is a significant component of the water budget of Hipps Pond.
3) Groundwater gradients are very low; the sediments at the site are quite permeable. The hydraulic gradients indicate that groundwater flow is generally toward the southeast, toward King's Creek and the York River.

Table 2.1. Soil descriptions from well boring logs. For locations of wells, refer to Figure 2.3.

Location	Depth interval (m)	Description
UVAPZ1	0.00-0.91	Fine sandy silt, moist,brown
	0.91-1.52	Fine silty sand, wet,brown,water at 1.28
	1.52-2.53	Fine well sorted sand,trace silt, wet
UVAPZ2	0.00-0.85	Fine to medium silty sand,moist, brown to red-brown
	0.85-1.16	Fine sand,trace silt,moist,tan
	1.16-1.62	Fine silty clayey sand,moist, slightly cohesive and mottled
	1.62-2.53	Sandy lean clay,trace gravel,moist gray and brown
	2.53-2.83	Silty clay,moist,mottled,brown
	2.83-3.81	Coarse sandy clay, moist,brown
	3.81-4.88	Coarse clayey sand,wet,saturated at 3.96m, contains shell fragments at 4.88m
UVAPZ3	0.00-1.37	Fine sand with silt,moist,brown
	1.37-3.05	Fine sand with clay,moist,brown
	3.05-5.18	Fine to medium clayey sand,mottled,brown
	5.18-6.71	Fine to medium silty sand,wet, contains shell fragments; saturated at 5.18
UVANW3	0.00-1.16	Fine sandy silt,moist
	1.16-1.83	Silty clay,moist, consolidated
	1.83-2.19	Fine to coarse clayey sandy gravel, wet; saturated at 1.83
UVANW4	0.00-1.28	Sandy silt with clay, moist,consolidated
	1.28-1.52	Fine sandy clay (CL),saturated,blue-gray
UVANW5	0.00-1.52	Fine well sorted sand,silty, moist,brown
	1.52-1.83	Silty clay with sand,moist,consolidated, mottled,brown
	1.83-2.44	Sandy gravel with clay,wet,yellow-brown

General observations for groups of wells:

UVANW1/NW2, UVANW6/NW7, UVANW8/NW9: Well sorted medium grained sands with silt and gravel; contains lenses of leaves and organic material

UVALP1/LP2, UVALP3, UVALP4/LP5: Sandy silty clay with peat and organic silt; saturated; strong odor of petroleum product

Table 2.2. Conductivity and pH measurements of surface water and groundwater in the North Branch and adjacent wells, respectively. Measurements were taken on 21 June, 1990 during a base flow period. For locations of wells and sampling stations, refer to Figure 2.3.

Sample location	pH	Conductivity (μS/cm)
Groundwater		
UVANW-6	7.0-7.5	600
UVANW-7	7.0-7.5	510
UVANW-9	7.0-7.5	700
UVANW-8	7.5	700
UVANW-11	7.5	440
UVANW-10	7.0-7.5	435
UVANW-3	7.0-7.5	505
UVANW-2	7.0-7.5	590
UVANW-1	7.0-7.5	310
UVANW-4	7.5-8.0	650
Surface water		
Injection site		530
Station 1		600
Station 2	7.0-7.5	600
Station 3	7.0-7.5	510
Station 4	7.0-7.5	550
Station 5	7.0-7.5	520
Station 6	7.0-7.5	520
Station 7	7.0-7.5	500
Station 8	7.0-7.5	500
Station 9	7.0-7.5	490
Station 10	7.0-7.5	500

Table 2.3. Storm events during field season.

Storm	Julian Date	Date	24-hour time	Rainfall amount (cm)
1	142	05/22	100	
	142	05/22	1800	2.25
2	146	05/26	2030	
	147	05/27	1430	2.50
3	149	05/29	200	
	149	05/29	2000	2.38
4	154	06/03	1900	0.63
5	165	06/14	---[a]	
	172	06/21	---[a]	1.25
6	173	06/22	1600	0.38
7	181	06/30	2000	2.25
8	192	07/11	1800	
	193	07/12	600	1.25
9	194	07/13	2200	0.75
10	195	07/14	1200	0.50
11	197	07/16	1800	0.50
12	198	07/17	1700	7.25
13	202	07/21	1600	2.50
14	218	08/06	2000	
	219	08/07	400	2.75
15	221	08/09	400	1.88
	221	08/09	1700	1.75
16	227	08/15	1800	3.13
17	231	08/19	1500	1.75
18	236	08/24	200	
	236	08/24	1300	2.50
19	256	09/13	800	
	256	09/13	1600	2.8

[a] = time of storm event unknown

Table 2.4. Summary of University of Virgina field instrumentation. For locations of instruments, refer to Figures 2.2 and 2.3.

Instrument	Elevations Top of casing (m)	 At ground surface (m)	Depth of screened interval top (cm)	 base (cm)
UVAMW-15	7.46	6.93	61	107
UVAMW-14	8.34	7.85	61	104
UVAMW-13	8.73	8.19	61	107
UVAMW-12	9.24	9.16	82	143
UVAMW-11	10.48	10.47	131	177
UVAMW-10	9.95	9.55	67	113
UVAMW-9	10.18	9.30	23	68
UVAMW-8	9.77	9.30	64	107
UVAMW-7	10.31	9.40	15	64
UVAMW-6	9.89	9.40	61	105
UVAMW-5	11.79	10.86	183	244
UVAMW-4	9.67	9.24	86	124
UVAMW-3	10.45	10.28	186	216
UVAMW-2	8.78	8.35	74	104
UVAMW-1	9.38	8.33	18	48
UVAPZ-4	7.23	6.71	193	254
UVAPZ-3	11.41	10.35	533	610
UVAPZ-2	9.52	8.19	655	732
UVAPZ-1	5.39	4.58	244	274
UVALP-1	4.58	3.85	91	152
UVALP-2	4.50	3.76	15	76
UVALP-3	4.00	3.76	107	134
UVALP-4	4.11	3.7438	48	84
UVALP-5	4.98	3.74	85	116
Tensiometers				
T4	4.68	4.30		52
T10	5.00	4.50		78
T12	4.87	4.13		58
Flumes				
North Branch		9.13		
Discharge Stream		0.58		

Table 2.5. Summary of head differences (in cm.) among nested piezometers in the North Branch channel.

Well nest	UVAMW-9 UVAMW-8	UVAMW-7 UVAMW-6	UVAMW-2 UVAMW-1
average difference	2.5	8.1	7.5
standard deviation	2.9	10.0	12.2

Table 2.6. Summary of stream lengths and corresponding drainage sub-areas delineated for inflow estimates to Hipps Pond. Groundwater contributing areas and storm-flow source areas were measured from the site map (Fig. 2.1) and the survey map (Fig. 2.3), respectively.

	Site Map		**Survey map**		
Drainage area ID *	Length (m)	Area (m^2)	Length (m)	Flood plain width (m)	Flood plain area (m^2)
NB-TOP	107	49600	122	3	370
NB-1	30	8000	30	3	90
NB-2	30	6200	34	3	100
NB-3	30	5100	30	6	190
NB-4	30	4900	30	6	190
NB-5	60	16400	60	8	470
NB-6	90	16500	60	9	560
NB-7	160	39500	80	15	1260
NB-8	130	23000	210	23	4900
NB-9	80	18000	76	26	2000
NBTR-TO		23400			
NBTR-1	70	5000			
NBTR-2	100	6000	90	5	420
Total NB	980	227000	800		10500
SB-TOP		44200			
SB-1	110	21200	80	5	350
SB-2	90	10500	110	6	650
SB-3	90	7000	80	9	700
SB-4	110	9500	160	26	4200
SBTR-TOP		19300			
SBTR-1	70	5700	100	3	300
SBTR-2	120	9500	110	1	130
Total SB	600	120000	600		6200
MC-TOP		26000			
MC-1	210	41400	210	3	630
SL		43000			
NL		46000			
TOTALS	1800	503500			17200

* for explanation of drainage area IDs, see Table 2.6a.

Table 2.6a. Explanation of drainage area IDs referred to in Table 2.6.

Drainage area ID	Explanation
North Branch	
NB-TOP	North Branch above injection point to headwaters
NB-1	Injection point to station 1A
NB-2	Stn. 1 to Stn. 2
NB-3	Stn. 2 to Stn. 3
NB-4	Stn. 3 to Stn. 4
NB-5	Stn. 4 to Stn. 5
NB-6	Stn. 5 to major trib entrance
NB-7	confluence with major trib (NBTR) to major south bend
NB-8	major bend to NB/SB confluence
NB-9	below NB/SB confluence to inflow culverts of Hipps Pond
NBTR-TOP	headwater area of major tributary of North Branch
South Branch	
SB-TOP	South Branch headwater area
SB-4	below trib confluence to confluence with North Branch
SBTR-TOP	headwater area of major tributary of South Branch
Marsh Creek	
MC-TOP	"marsh creek" headwater area
Direct drainage areas into Hipps Pond	
SL	South drainage area of Hipps Pond
NL	North drainage area of Hipps Pond

Table 2.7. Summary of stream dilution gaging results. See Table 2.6a for explanation of drainage area IDs. See Figure 2.3 for location of sampling stations.

Drainage Area ID	Sampling station	Inflow rate (L/s)	Length between stations (m)	Drainage area (m^2)	Inflow per unit length (L/s m)	Inflow per unit area (L/s m^2)
NB-1	1					
NB-2	2	0.12	38	6200	3.2E-03	1.9E-05
NB-3	3	0.11	31.	5200	3.5E-03	2.1E-05
NB-4	4	0.11	31	5000	3.5E-03	2.2E-05
NB-5	5	0.32	61	16400	5.2E-03	2.0E-05

Table 2.8. Inflow rates measured with in-stream seepage meters on the North Branch. For locations of stations, refer to Figure 2.3.

Location	Sample period start	end	Flux (m/day)
Station 1	07/02	07/09	5.0E-04
	07/09	07/12	9.5E-04
	07/17	07/24	3.9E-04
Station 2	06/06	06/06	5.5E-03
	06/07	06/07	1.7E-02
	06/13	06/13	1.1E-02
Midway between stations 3 and 4	07/03	10/18	0
Station 4	06/07	06/13	5.0E-04
	06/13	06/21	4.5E-04
	06/21	06/27	5.3E-04

Table 2.9. Summary of groundwater gradients. See Figures 2.2 and 2.3 instrument locations.

	Transect		Date	
	Upper	Lower	7/2/90	8/24/90
Hipps Pond				
Lateral				
	UVALP-3	Pond	0.03	0.005
	ESIMW-13	Pond	0.02	0.022
	ESIMW-13	ESIMW-9	0.022	0.027
	ESIMW-9	Pond	0.005	0.004
	ESIPZ-2	Pond	0.034	0.03
	UVAPZ-1	Pond	0.012	0.007
	UVAPZ-2	Pond	0.014	0.011
	UVAPZ-3	Pond	0.013	0.01
	UVAPZ-3	UVAPZ-2	0.009	0.007
	UVAPZ-2	UVAPZ-1	0.015	0.013
Vertical				
	UVALP-1	UVALP-2	0.012	0.32
	UVALP-4	UVALP-5	0.22	0.21
	UVALP-5	Pond	0.061	0.041
	UVALP-2	Pond	0.043	0.033
South Branch				
Lateral				
	ESIMW-11	ESIMW-12	0.007	0.007
	ESIMW-11	creek level	0.01	0.008
	ESIMW-10	creek level	0.013	0.011
	ESIMW-12	creek level	0.012	0.01
	ESIMW-7	creek level	0.032	0.025
	ESIMW-4	creek level	0.043	0.039
	ESIMW-3	creek level	0.047	0.049
	ESIMW-2	creek level	0.051	0.043
	UVANW-14	creek level	0.051	0.048
	UVANW-4	creek level	0.06	0.07
	UVANW-5	creek level	0.042	0.036
	UVANW-10	creek level	0.055	0.087
	UVANW-11	creek level	0.042	0.050
	UVANW-11	UVANW-10	0.033	0.026
Vertical				
	UVANW-1	UVANW-2	0.21	
	UVANW-6	UVANW-7	0.125	
	UVANW-8	UVANW-9	0.045	

Table 2.10. Comparison of estimated groundwater inflows to the North Branch. For locations of piezometer nests, refer to Figure 2.3.

	TOTAL INFLOW[a]	LATERAL INFLOW[b]	VERTICAL[c]	VERTICAL[d]
location	measured (m^3/day m)	calculated (m^3/day m)	measured (m^3/day m)	calculated (m^3/day m)
UVANW-1/NW-2	2.7E-01	3.6E-01[e] 3.6E-02[f]	2.5E-04 (1.8E-05)[h]	9.1E-02[f] 9.1E-03[g]
UVANW-6/NW-7	2.7E-01	3.6E-01[e] 3.6E-02[f]	5.7E-03 (2.4E-03)[h]	5.4E-02[f] 5.4E-03[g]
NW-8/NW-9	2.7E-01	3.6E-01[e] 3.6E-02[f]	3.1E-04 (1.2E-04)[h]	1.9E-02[f] 1.9E-03[g]

Method:

[a] = in-stream dilution experiment
[b] = Darcy's law with observed water levels
[c] = in-stream seepage meters
[d] = Darcy's law with observed heads

Estimated hydraulic conductivites:

[e] = K = 1E-02 cm/s
[f] = K = 1E-03 cm/s
[g] = K = 1E-04 cm/s

[h]Numbers in parentheses represent 1 standard deviation from the mean.

Table 2.11. Monthly water budget on Hipps Pond.

	INPUTS				OUTPUTS				
	Surface								
Month	Base Flow	Storm Flow	Rain	Ground Water	Outfall Discharge	PET	Dam Seepage	**STORAGE**	**RESIDUAL**
July	10000	2500	3200	48	12000	8000	58	-1200	-3700
August	8100	2000	3500	46	8600	5200	56	800	-1000
September	5100	900	700	48	3800	3400	58	-1200	600

A negative value for storage change indicates a net loss of water in the pond.

A positive value for storage change indicates a net gain of water in the pond.

A negative residual indicates that the sum of outputs and storage exceeds the total input. A negative residual results if total inputs exceed the sum of outputs and storage.

Table 2.12. Contributions of water budget components of Hipps Pond for selected base flow intervals. All components expressed as fluxes over Hipps Pond area.

Date start	Date end	Total input[a] (cm/d)	Pond stage drop (cm/d)	Outfall discharge (cm/d)	PET (cm/d)	Residual[b] (cm/d)
07/02	07/09	1.12	0.47	1.02	1.10	-1.47
07/09	07/11	0.78	0.22	0.62	1.26	-1.33
07/27	07/31	2.27	0.42	0.78	0.88	0.20
07/31	08/03	2.01	0.36	0.45	0.83	0.36
08/03	08/06	1.78	0.12	0.28	0.83	0.55
08/25	09/04	0.89	0.60	1.23	0.69	-1.63
09/04	09/13	0.67	0.08	0.39	0.55	-0.35

[a] Total input = direct groundwater and surface water into Hipps Pond.

[b] A negative residual indicates that the sum of outputs and storage exceeds the total input. A negative residual results if total inputs exceed the sum of outputs and storage.

Table 2.13. Fluxes of major components into Hipps Pond during selected storm intervals. Each value represents the flux over the pond area.

Date	Rain (cm)	Total surface runoff[a] (cm)	Lake level rise (cm)	Total output[b] (cm)	Residual[c] (cm)
06/30	2.25	2.3	3.5	1.1	-0.2
07/11	1.25	0.8	1.4	1.5	-0.8
07/17	7.25	5.1	8.7	3.4	0.2
07/21	2.5	3.0	5.0	1.3	-0.8
08/06	2.75	0.8	4.5	1.4	-2.4
08/19	1.75	1.2	2.5	1.7	-1.2

[a] Total surface runoff = storm flow from all creeks.

[b] Total output = total storm minus related discharge through the outfall stream.

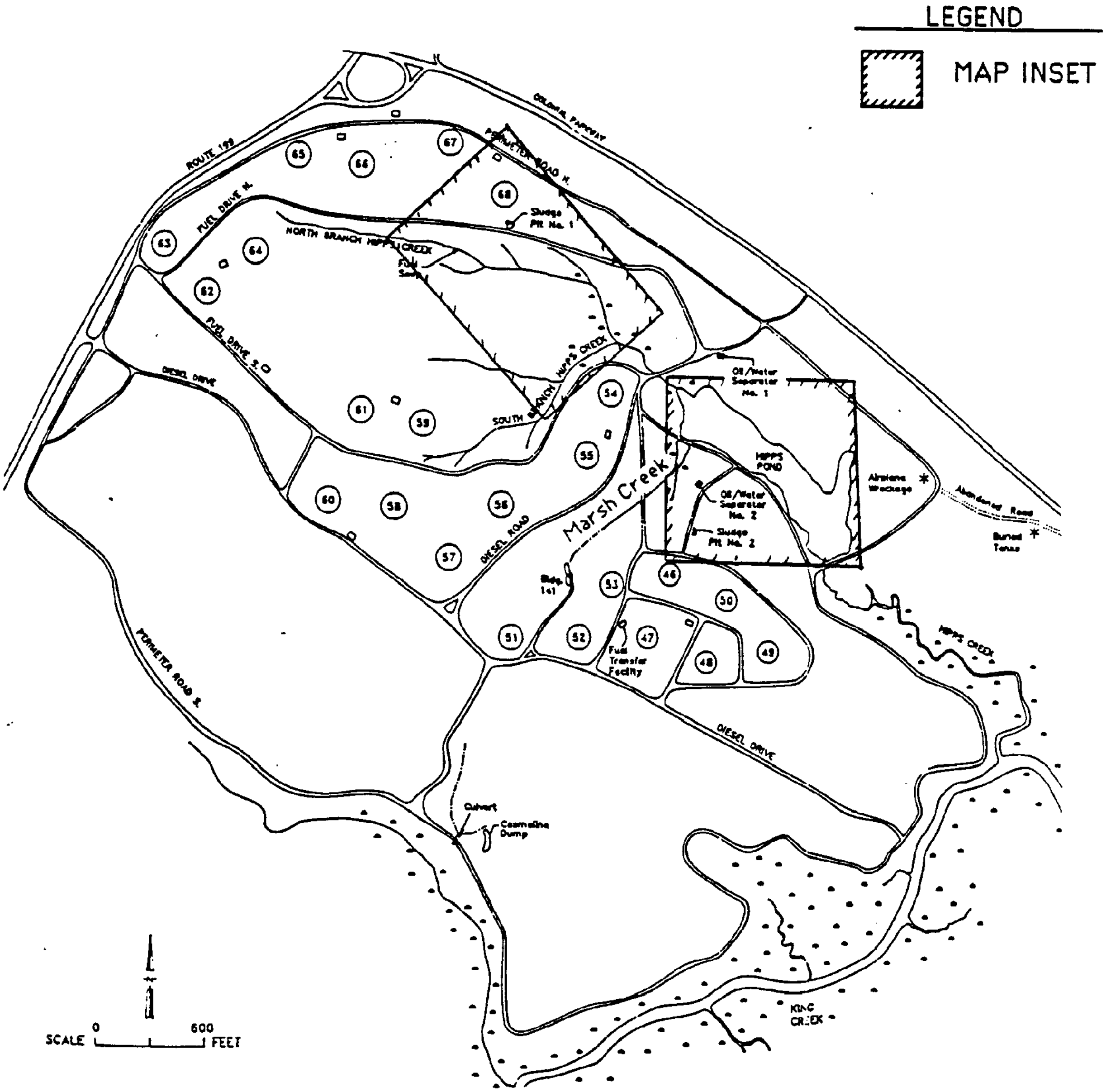
[c] A negative residual indicates that the sum of outputs and storage exceeds the total input. A negative residual results if total inputs exceed the sum of outputs and storage.

Table 2.14. Estimated uncertainties in monthly water budget components of Hipps Pond. Adapted in part from Winter (1981).

Component	Percent Error
PRECIPITATION	
Gauge	3
Placement	5
Areal Averaging	5
Gauge Density	10
Total Error	**23**
POND EVAPORATION	
Energy Budget	25
Pond Area	10
Total Error	**35**
STREAM FLOW IN	
Base flow	
Stage-Discharge Relationship	5
Channel Bias	5
Areal Groundwater Inflow Rel.	100
Total Error	**110**
Storm Flow	
Stage-Volume Relationship	45
Area-Yield Relationship	130
Total Error	**175**
STREAM FLOW OUT	
Stage-Discharge Relationship	5
Channel Bias	2
Total Error	**7**
LAKE STORAGE	
Lake Area	10
Stage-Water Level Record Rel.	5
Total Error	**15**
DIRECT GROUNDWATER INFLOW	
Gradient	15
Flux Area	20
Hydraulic Conductivity	200
Total Error	**235**
DAM SEEPAGE	
Gradient	15
Flux Area	20
Hydraulic Conductivity	200
Total Error	**235**
Overall Error	777 %

Figure 2.1

CHEATHAM ANNEX
SITE MAP



(Taken from: ESI, 1989)

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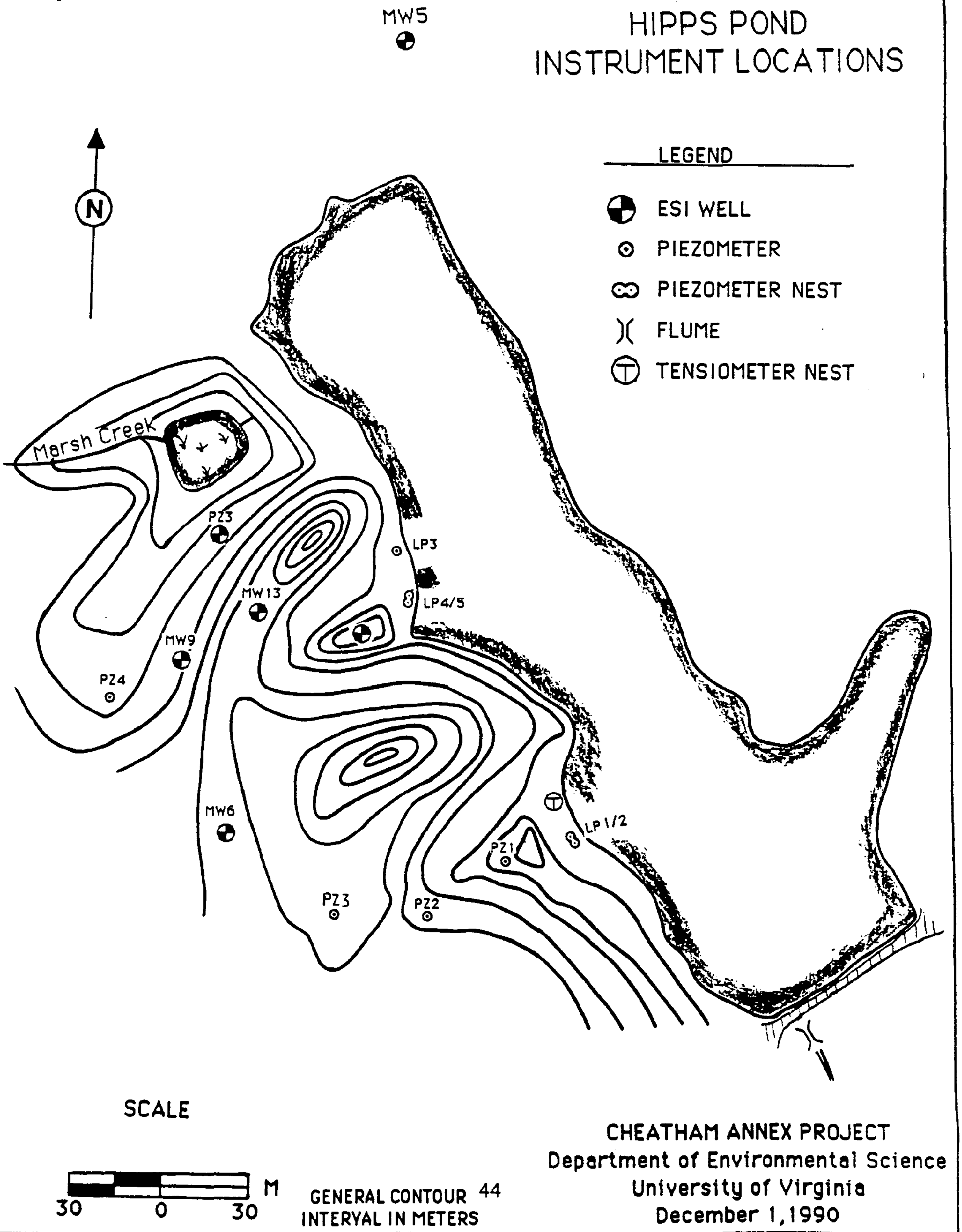
December 1, 1990

Figure 2.2



HIPPS POND
INSTRUMENT LOCATIONS

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December 1,1990

Figure 2.3 NORTH BRANCH
INSTRUMENT LOCATION AND SAMPLING STATIONS

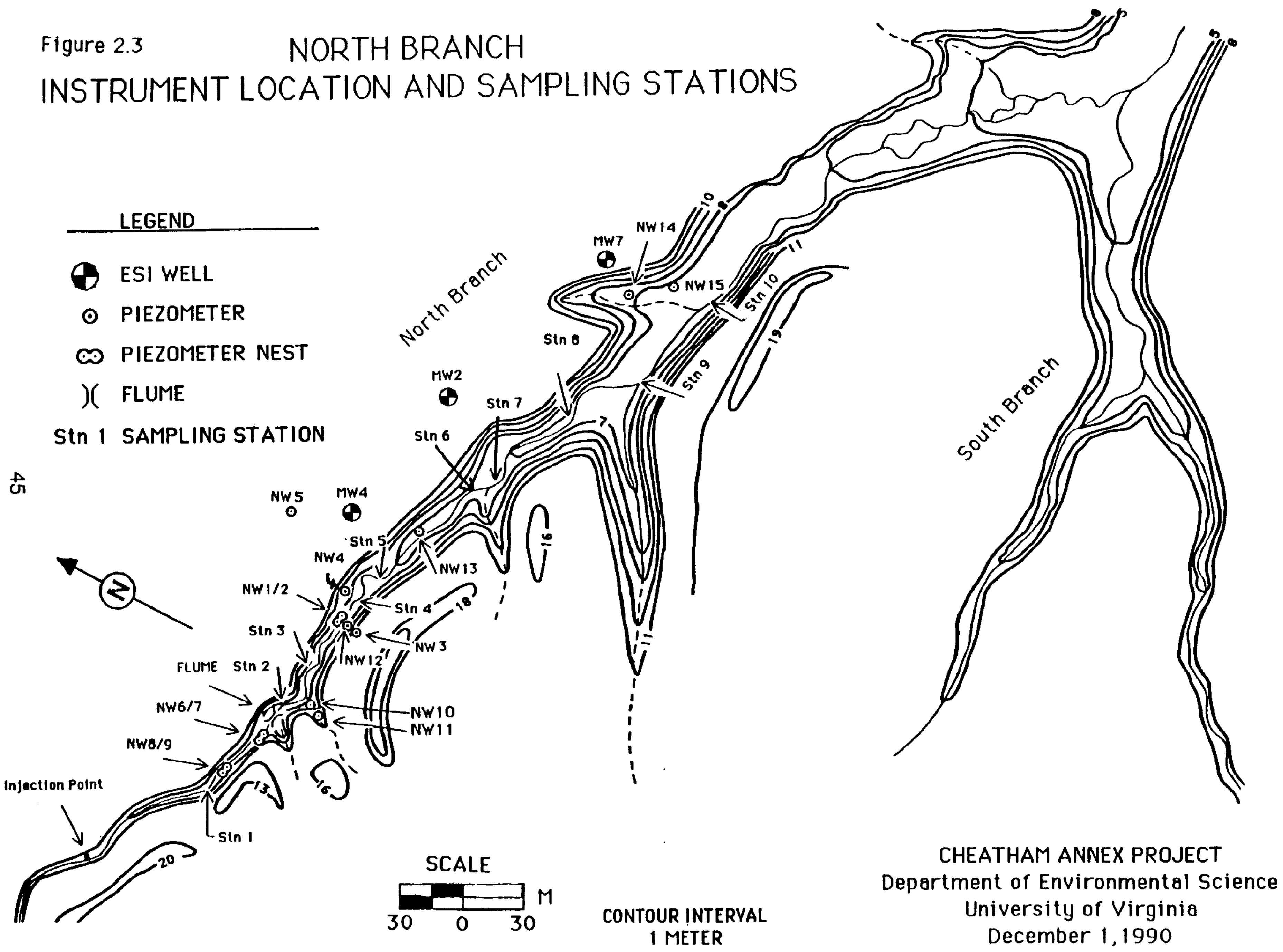

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Figure 2.4

NORTH BRANCH FLOODPLAIN DELINEATION

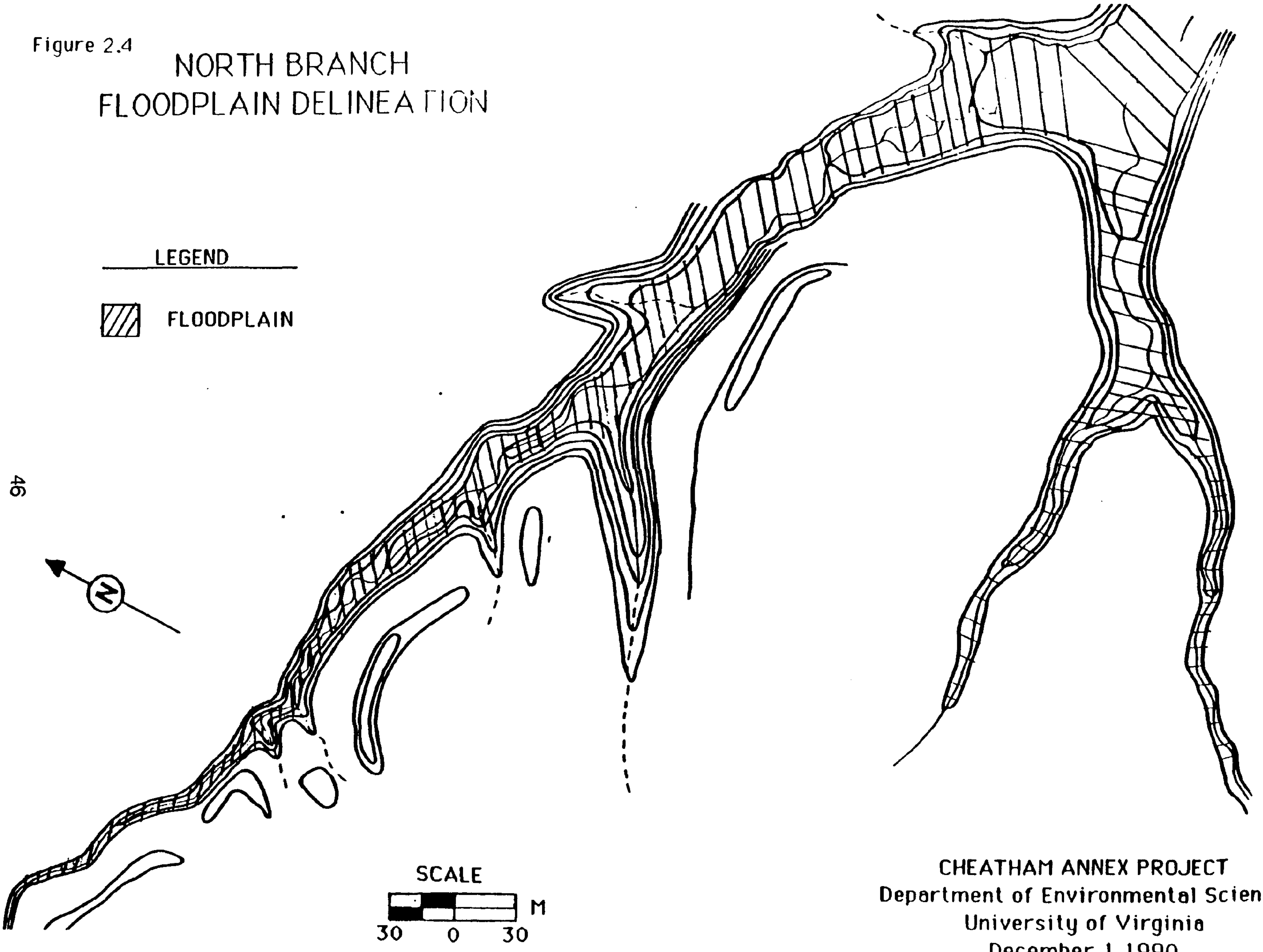

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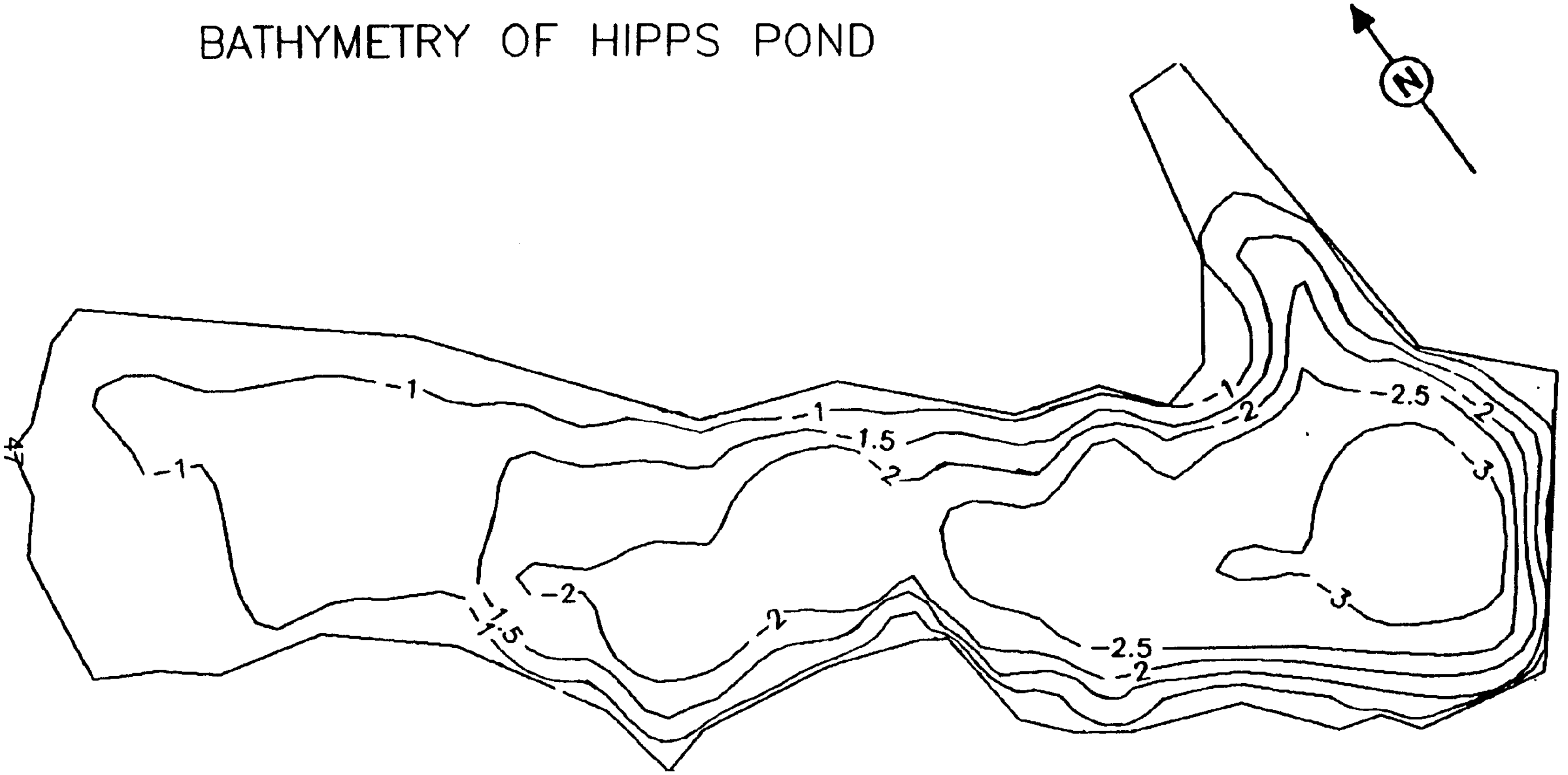
Figure 2.5

BATHYMETRY OF HIPPS POND



CONTOUR INTERVAL
0.5 METERS

SCALE 1:38

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Figure 2.6. Pond response to a storm event. In nearly all pond storm hydrographs, stage increased rapidly and stabilized to a near-constant height.

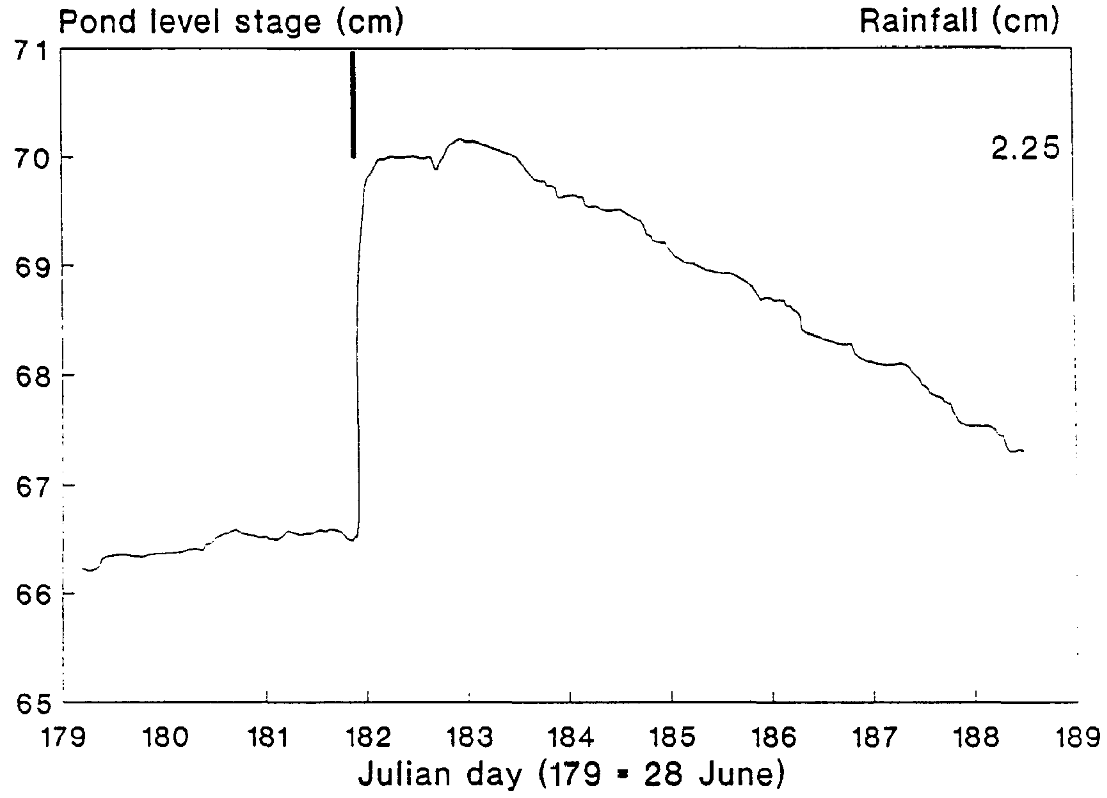

Figure 2.7. Comparison of response traces during and following a storm event. The wide variability of the tensiometer record against the "actual" lake response is evident.

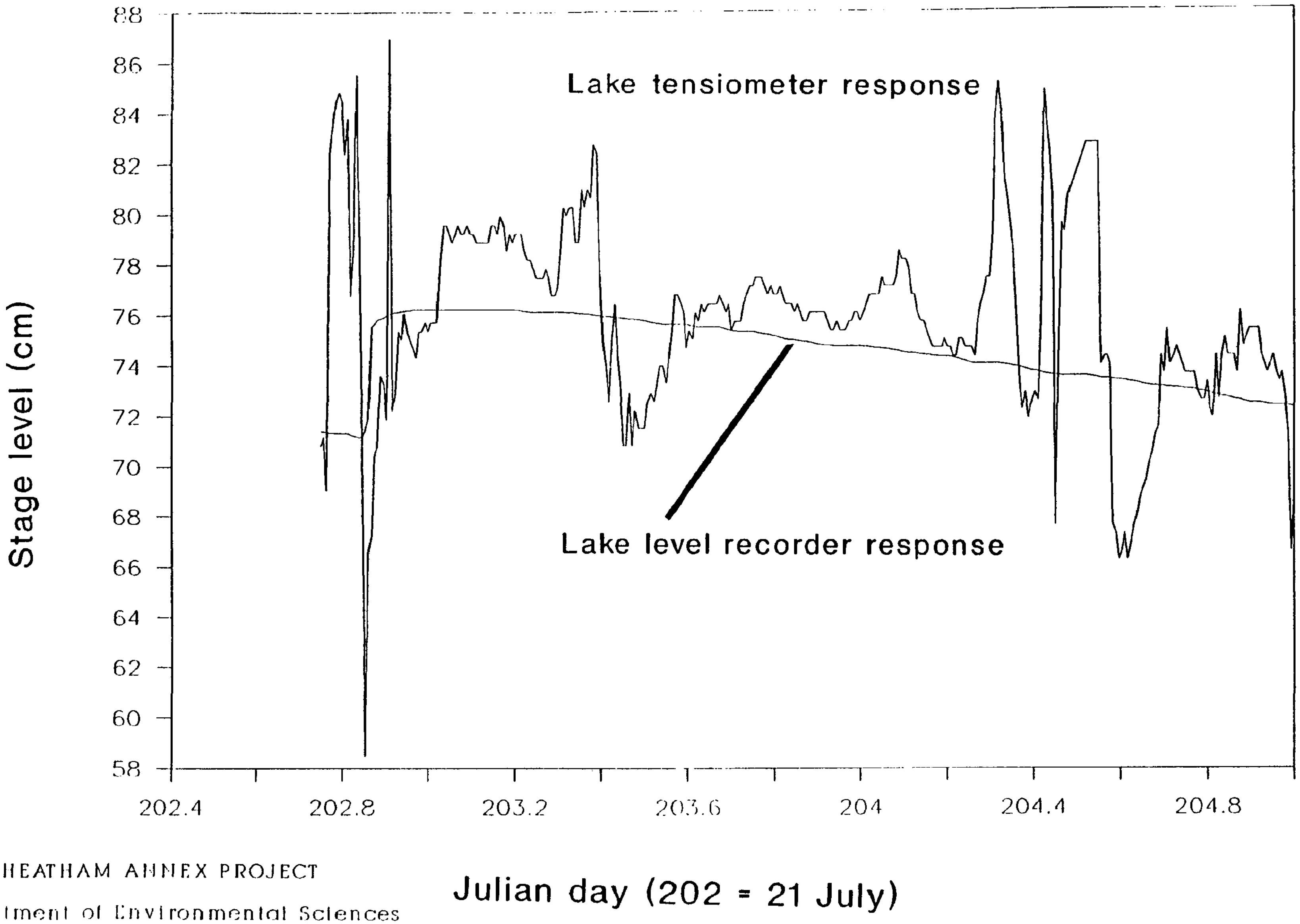

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Figure 2.8. Daily temperature cycles over a three-day period. This record extends over the same period as in Figure 2.7.

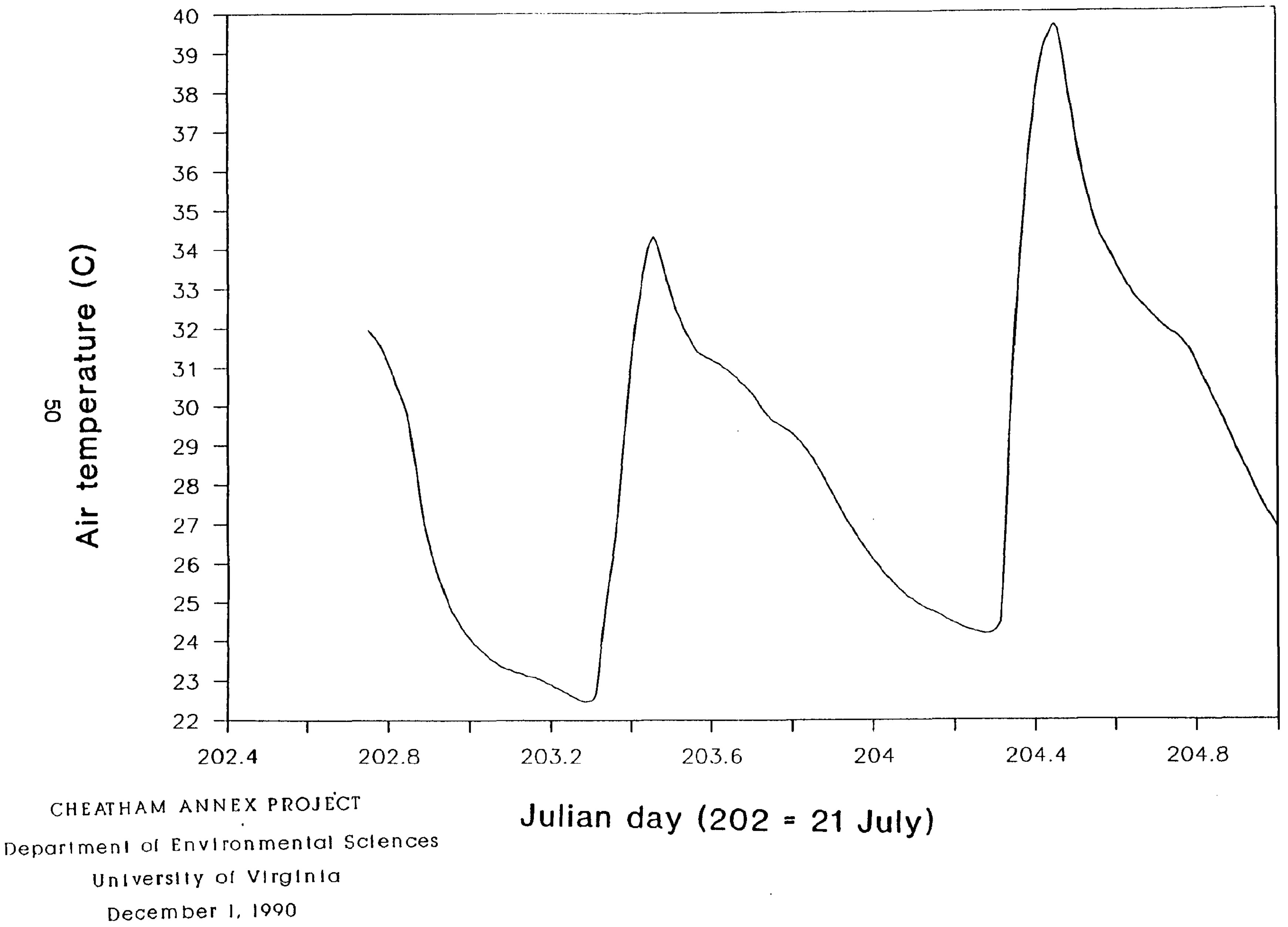

Figure 2.9. North Branch responses to three storm events.

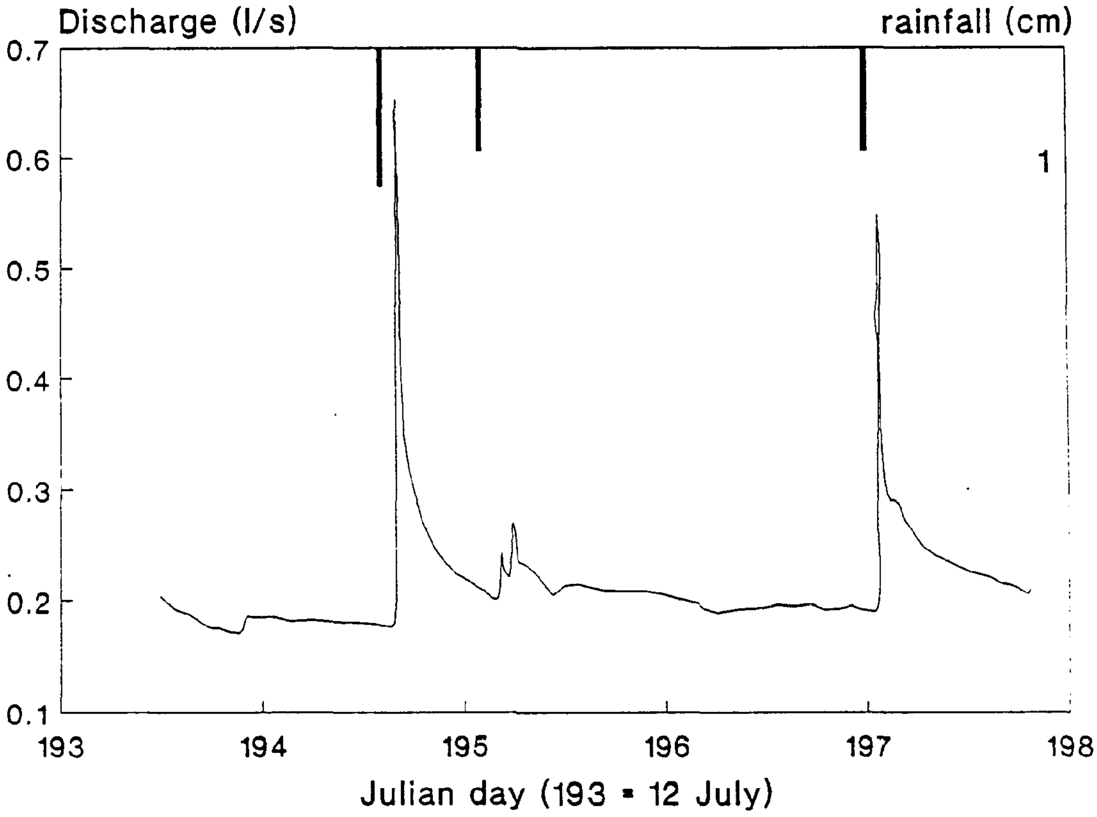

Figure 2.10. Subsurface responses near the North Branch to three storm events. The highest responses generally cluster in floodplain and riparian areas of the creek.

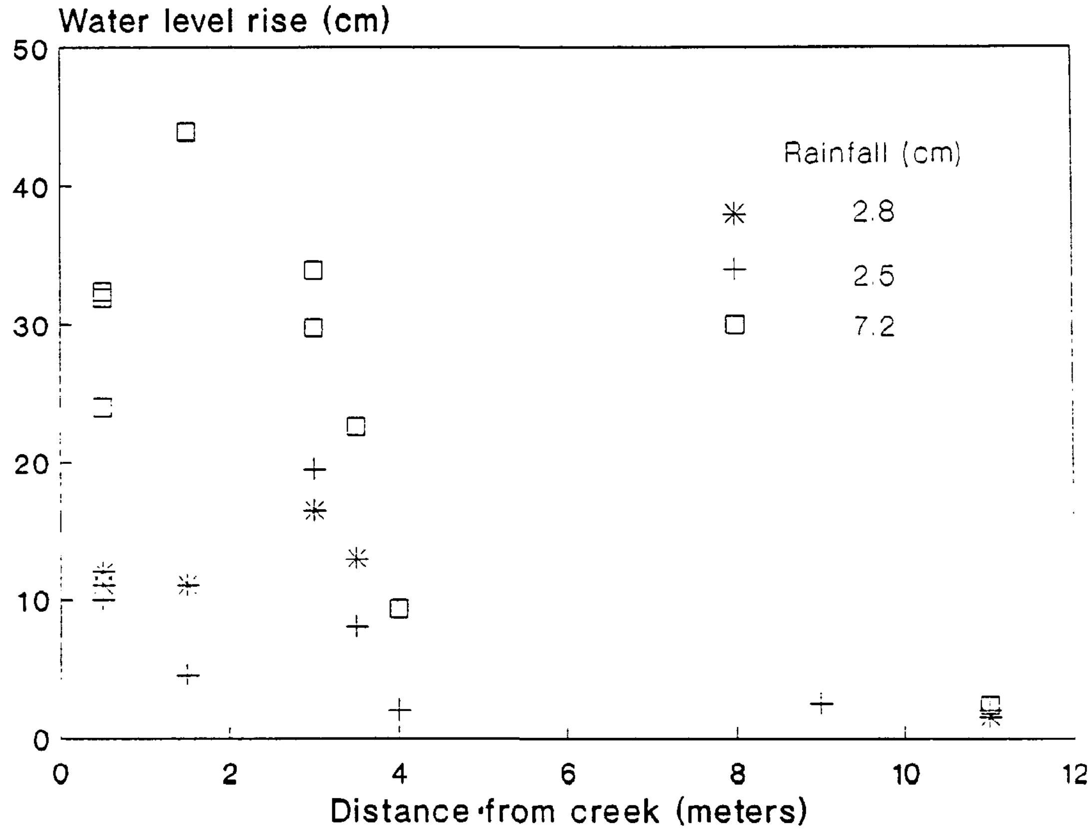

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Figure 2.11. Runoff yields from the North Branch floodplain above the flume for a series of storms.

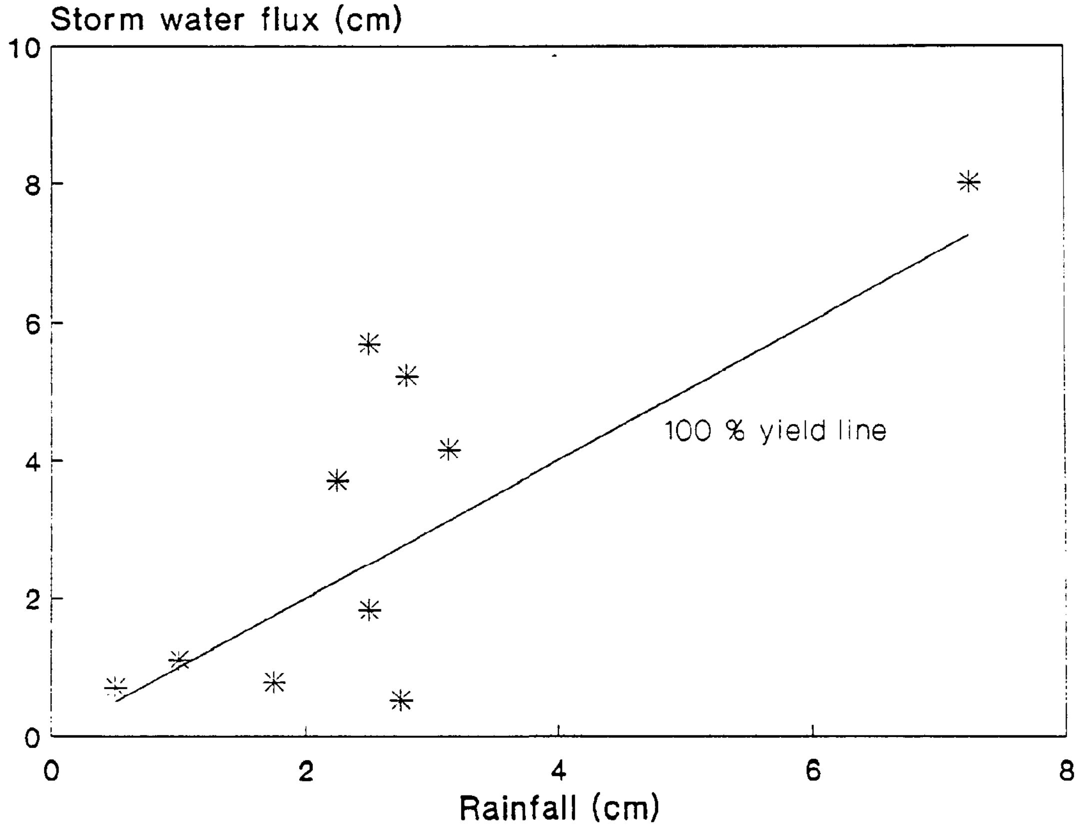
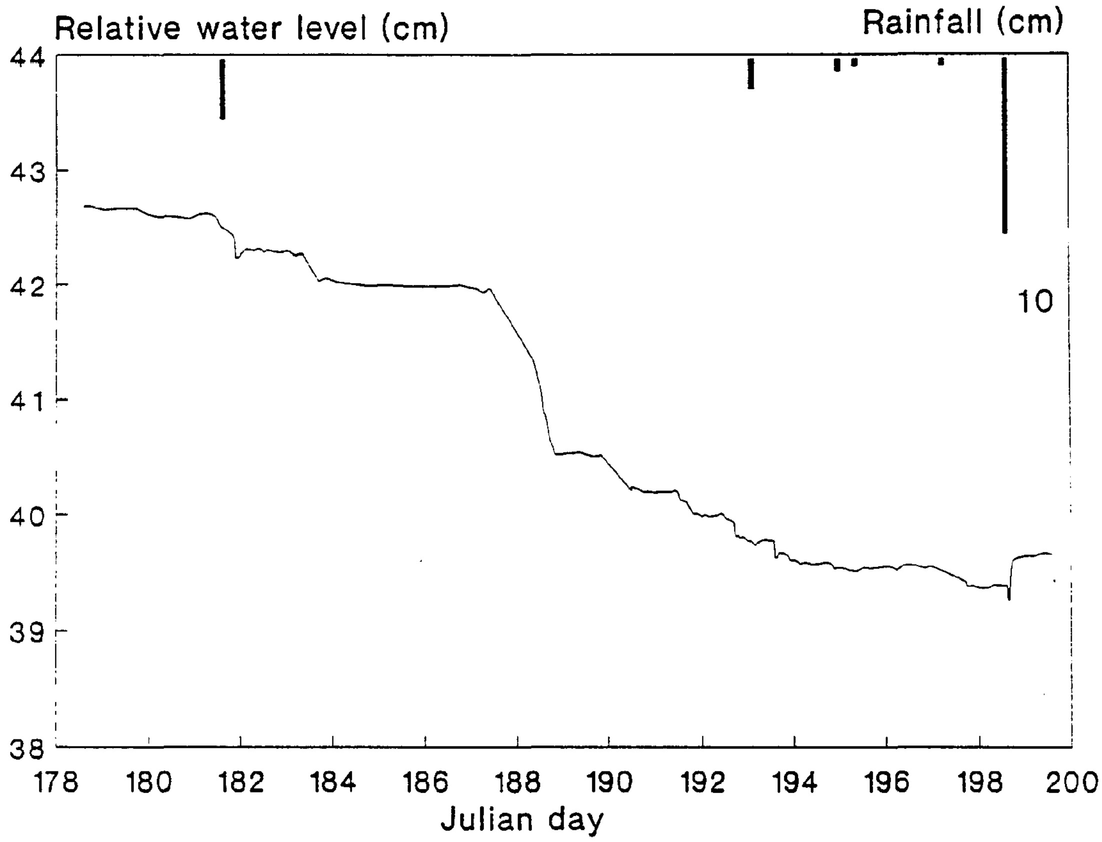


Figure 2.12. Water levels records from well UVAPZ-1 during a series of storms. Even during the largest storm, the water level rise is relatively minimal compared to weekly drawdowns.



III. ORGANICS

IIIA. Introduction

During its period of operation the Cheatham Annex site was used as a repository for a variety of petroleum products. Several spills and leaks on site have been documented, and interviews with former employees revealed the presence of several waste disposal pits which contained mixed sludges of unknown composition. Initial investigations by Engineering-Science, Inc. (ESI) under contract to the Virginia Deparment of Waste Management (VDWM) also indicated that a cosmoline dump existed in the southern portion of the site.

Given the nature of the materials stored on site and the operational history of the Cheatham Annex site the potential existed for contamination of environmental media by petroleum products. It was also recognized that incidental spills in the vicinity of loading/unloading valve boxes and oil/water separators would be expected and not uncommon. The prospect of leaking storage tanks poses a greater threat to the site as a whole, relative to the more confined regions, but definitive evidence of such an occurrence is possible only by adopting an aggressive excavation program. Such an approach is currently undesirable. It was decided, therefore, that the extent of potential contamination would be assessed through the collection and analysis of sediment, surface water, and well water samples. These samples were collected under the assumption that the Hipps Creek - Hipps Pond system is currently the dominant hydrologic force in the system and the primary route through which material from the subsurface is exported from the site.

IIIB. Methods

Collection of Samples for Organic Analysis

The location and nature of all samples collected for organics analyses are summarized in Table 3.1. All samples are described in Appendix I.

Water Samples

The water samples were collected by submerging the sampling jars 1-5 cm below the surface. The jars were filled completely and no air was allowed to remain in the jars as they were sealed. The samples were collected and stored in either 0.5-L amber or 1-L red Teflon-coated glass jars with screw lids. The samples were placed in an ice-filled cooler and later stored under refrigeration prior to analysis. During the collecteion procedure rubber gloves were worn at all times.

The pond water samples were collected before the sediment samples in each location. This prevented contamination of the water sample by agitated bottom sediments.

Groundwater samples were collected from wells installed at least three weeks previous to the collection date (see section IIC of this report for well construction details). A minimum of three well volumes of water were evacuated from each well prior to sampling. Most samples were collected using a stainless steel WILCO sampler which was rinsed with deionized water before each sample was collected. Sample LP-3 was collected from a one-inch-diameter piezometer which was too small for the Wilco sampling device; this sample was collected using a Nalgene hand pump fitted with Tygon tubing.

Sediment Samples

The two mid-pond sediment samples (S-4, S-5) were collected using a steel Wilco sediment bucket sampler. Samples were collected to a depth of 10 cm below the sediment-water interface. During sampling rubber gloves were used at all times. The bucket was rinsed after each sample was collected.

The pond-side sediment sample (S-6) was collected using a hand auger which collected to a depth of 15 cm. The North Branch floodplain sediment sample (S-7) was collected using a shovel to a depth of 5 cm.

No further effort was made to separate distinct layers of sediment; thus, all samples analyzed were of integrated sediment. All sediment samples were placed in sealable plastic bags from which as much air as possible was removed. The samples were placed in a cooler filled with ice and frozen immediately upon return to the lab.

Laboratory Methods

Prior to use, all glassware was rinsed with fresh solvent (methylene chloride; CH_2Cl_2), acid washed in a solution of Nochromix (Godax Laboratories, New York) and sulfuric acid (H_2SO_4), triple rinsed with deionized water and oven dried. The methylene chloride used was Burdick and Jackson Chrompure HPLC solvent (catalogue no. CP80175-4; Baxter, Burdick and Jackson Division, Muskegon, MI).

Sediment samples were extracted in a Soxhlet apparatus using 250 mL of CH_2Cl_2 as the extraction solvent. At the time of analysis, samples were thawed and homogenized, five replicate cores (approximately 3 g each) were collected and placed in tared, single-thickness cellulose extraction thimbles (Whatman, catalogue no. 2800-258). The total mass of the sediment plus thimble was recorded and the mass of sediment collected for extraction was determined. The composite sample was mixed with an equal mass of anhydrous sodium sulfate (Na_2SO_4) in the extraction thimble, and the thimble was then placed in the Soxhlet apparatus. Sediment samples were extracted for 16 hours. The heat source was adjusted such that the samples were extracted at the rate of approximately 20 minutes per cycle.

Upon completion of the extraction procedure, The extract was dried over anhydrous Na_2SO_4 and transferred to a Kuderna-Danish (K-D) concentration apparatus equipped with a three-ball macro Snyder column. The K-D apparatus was immersed in a hot water bath, and the extract was concentrated to an apparent volume of ~4 mL. The concentrated extract was allowed to cool, and the final volume of extract was recorded. A subsample of the concentrated extract was transferred to a 2-mL glass serum vial which was subsequently sealed with a crimp seal with a Teflon-lined rubber septum. The vial was filled and sealed to allow for minimal headspace. These sealed samples were stored at 4° C until analysis by gas chromatography could be performed. A 1-mL subsample of the concentrated extract was transferred to a tared 2-mL glass serum vial. The vial was not sealed and the solvent was allowed to volatilize off after which the vial was reweighed. The difference in weight was recorded and used in the calculation of total extractable hydrocarbons.

Water samples were filtered through Whatman number 4 qualitative filters, and a measured volume of the filtered sample was extracted with 200 mL CH_2Cl_2 in a continuous liquid-liquid extraction apparatus (catalogue no. 584210-0000; Kontes, Vineland, NJ). Samples were extracted for 48 hours. Upon completion of the extraction procedure, the CH_2Cl_2 fraction was collected, dried over anhydrous Na_2SO_4 and concentrated as detailed above.

Water samples WW-14 and WW-15 were filtered through tared Whatman number 1 qualitative filters. The aqueous filtrate was then extracted as detailed above for water samples. The filters were reweighed, and the filter and retained solids were extracted by Soxhlet extraction as detailed above.

Gas chromatography was performed on a Varian model 3300 gas chromatograph (Varian Associates, Sunnyvale, CA) equipped with a DB-5 fused silica capillary column (30 m x 0.32 mm i.d.; film thickness 0.25 μm; J&W Scientific, Folsom, CA) and flame ionization detector. Nitrogen was used as the carrier gas and the influent line was equipped with a moisture trap (gas filter model DGF-125; LabClear, Oakland, CA) and a hydrocarbon trap (Supelco rechargable hydrocarbon trap; Supelco, Inc., Bellefonte, PA). A splitless injection of 1.0 μL was made and the column oven temperature was programmed as follows: 85° C for 4 minutes, ramp to 270° C at 10° C per minute, hold at 270° C for 58 minutes. Injector and detector temperatures were maintained at 270° C. Chromatograms were recorded and the area under each peak was determined using a Varian model 4290 integrator.

Qualitative and quantitative analysis of sample chromatograms was achieved by comparison to standard chromatograms which were generated by analyzing a set of standard solutions of polynuclear aromatic hydrocarbons (PNA's)(PAH kit 610-S, catalogue no. 4-8755M; Supelco, Inc., Bellefonte, PA) under the chromatographic conditions set forth above.

IIIC. Results

All samples were analyzed for the presence of the sixteen PNA's listed in Table 3.2. For sediment samples, the concentrations of six of these compounds is listed. The remaining ten PNA's were not detected in any sediment sample analyzed. For water samples the concentration of fourteen PNA's is reported. The remaining two PNA's were not detected in any of the water samples analysed.

Tables 3.3 through 3.9 indicate the concentration of PNA's in sediment and water samples. Concentrations are reported in parts per million (ppm; micrograms per gram dry weight for sediment samples; micrograms per milliliter for water samples). Values in Tables 3.3 through 3.9 represent the mean (standard deviation) of three replicate injections per sample, except where indicated otherwise. Sampling locations are indicated on Figure 3.1.

All three sediment samples collected from Hipps Pond were found to contain PNA's (Table 3.3). Sample S-4 was collected from the northwest end of Hipps Pond near the surface water inflow. The analyses indicated that these sediments were dominated by acenaphthylene (78.22 ppm) and acenaphthene (40.93 ppm) with a total concentration of about 150 ppm PNA's. Sample S-6 was collected approximately one foot from the southern shore of Hipps Pond about midway along the length of the pond. Although this sample cotained a smaller overall mass of PNA's (99.40 ppm) it had a substantially higher mass of total extractable hydrocarbons (TEH). Sample S-5 was collected from the southeast end of Hipps Pond and also indicated elevated levels of acenaphthylene (86.11 ppm) and acenaphthene (45.19 ppm) with a total PNA value of approximately 10,000 ppm.

Sample S-7 was (Table 3.3) collected from the flood plain of the North Branch of Hipps Creek downstream from the sludge pit. Because acenaphthylene was detected in only one of three replicate chromatograms a reliable statement about the presence of this compound cannot be made. Sample S-7r (Table 3.4) was a replicate sample gathered from the flood plain of the North Branch. If present, the PNA's for which analyses were conducted were at levels below the limit of detection.

Sediment samples S-1, S-2, and S-3 were collected from seepage faces along Perimeter Road in the southeast quadrant of the site (Figure 3.1). Any PNA's present were below the limits of detection.

UVAPZ-4s and UVALP-3s (Table 3.5) represent the solid fraction which was filtered from water samples collected from UVAPZ-4 and UVALP-3 (see section IIC of this report for well construction details). UVAPZ-4 was located south of Hipps Pond upgradient of the marshy inflow to the pond. Analyses indicated that all compounds if present were below the limits of detection for sample UVAPZ-4s. Well UVALP-3 was installed approximately one foot from the edge of Hipps Pond about midway along the length of the southern edge of the pond. As indicated in the notes accompanying Table 3.5, the water sample collected from this well contained a much larger mass of suspended solids. Acenaphthylene, acenaphthene, and fluorene were detected in sample UVALP-3s. In terms of the results of the PNA anlysis UVAPZ-4s and UVALP-3s are very different, but these two samples appear to be similar in terms of TEH. It is important to note that the low mass of suspended solids in the water sample collected from UVAPZ-4 (1.56 g) resulted in substantially higher limits of detection for sample UVAPZ-4s relative to sample UVALP-3s.

Water samples SW-5(8/2) and SW-6(8/2) were collected in early August 1990 from the North Branch of Hipps Creek and South Branch of Hipps Creek, respectively (Table 3.6). samples A second round of samples were collected in early September 1990 [SW-5(9/3), North Branch; SW-6(9/3), South Branch; Table 3.7]. PNA's were not present above detection limits in any of these four samples.

Water sample SW-12 was collected from the swampy inflow area to the south of Hipps Pond (Figure 3.1). PNA's were not present above detection limits in this sample (Table 3.6). Sample SW-8(8/2) was collected from the outflow of Hipps Pond in early August 1990 (Table 3.6) and a second sample [SW-8(9/3), Table 3.7] was collected in early September. Neither sample contained PNA's at levels above the detection limit.

Water samples from the middle of Hipps Pond were gathered in early August 1990 from the northwest (LW-1+LW-1r) and southeast (LW-2+LW-2r) portions of the pond (Table 3.8, Figure 3.1). Several compounds were detected in sample LW-1+LW-1r but these compounds were detected in the same single chromatogram and were not detected in either of the other two replicate chromatograms. Analysis of sample LW-2+LW-2r indicated the presence of small amounts (0.16 ppm) of naphthalene.

Water samples SW-9, SW-10, and SW-11 were collected from seepage faces from the southeast quadrant of the Cheatham Annex site along Perimeter Road (Figure 3.1). Analyses indicate that PNA's are not present in samples SW-9 and SW-11 (Table 3.7 and 3.8, respectively). However, detectable amounts of acenaphthylene, phenanthrene, benzo(a)anthracene, indeno(1,2,3-c,d)pyrene, and dibenzo(a,h)anthracene were found in sample SW-10 (Table 3.8)

Water samples were collected from wells UVAPZ-4 and UVALP-3 and given the same ID number (Figure 3.1). All PNAs were below limits of detection for sample UVAPZ-4 (Figure 3.9) but small amounts of naphthalene (0.37 ppm) and acenaphthylene (0.52 ppm) were found in UVALP-3.

IIID. Discussion

Previous sampling schemes at the Cheatham Annex site were designed to locate and identify those areas within the site which are contaminated with petroleum products. In contrast, the sampling scheme used in the current investigation was designed to identify the extent of potential contamination within the site. Within this framework, it is recognized that smaller scale regions of high contaminant concentration may exist within a much larger region of relatively low or no contaminant concentration. Due to the differences in sampling philosophy, therefore, the results reported herein may not be directly comparable to previously reported results. It does remain possible to compare samples gathered from sites in close proximity to one another and these comparisons are made where relevant. However, one may generate diametrically opposite conclusions about the site as a whole due to the differences in sampling scheme previosly described.

Surface water samples which were gathered in August and September 1990 were generally free of contamination by PNA's. Surface water sample replicates SW-6(8/2) (Table 3.6) and SW-6(9/3) (Table 3.7), which were collected from the South Branch of Hipps Creek contained no detectable levels of PNA's and had very low quantities (<3 ppm) of total extractable hydrocarbons (TEH). These results are in agreement with those reported by ESI. PNA's and TEH in replicate water samples collected from the North Branch of Hipps Creek [SW-5(8/2), Table 3.6; SW-5(9/3), Table 3.7] were similarly absent and in low concentration, respectively.

Water samples from the second round of sampling collected from the discharge stream of Hipps Pond [SW-8(8/2), Table 3.6; SW-8(9/3), Table 3.7] contained no PNA's and also had low levels of TEH. These results also agree with those reported previously by ESI.

Several PNA's were detected in pond water sample LW-1+LW-1r (Table 3.8) but the presence of these compounds could not be reliably detected in replicate chromatograms. It is therefore doubtful that the compounds indicated in Table 3.8 are present at levels above detection limits. Pond water sample LW-2+LW-2r was also found to be free of high concentrations of PNA's. These results are also in agreement with those reported by ESI.

Well water sample UVAPZ-4 (Table 3.9) was collected near the swampy area to the south of Hipps Pond and downgradient of an oil/water separator. This sample was free of PNA's. However, sample UVALP-3 was contaminated with low concentrations of naphthalene and acenaphthylene. Naphthalene and acenaphthylene are both considered to be insoluble in water (CRC Handbook of Chemistry and Physics) and are more likely to be associated with the solid fraction of the sample. UVALP-3 had a large suspended solid load (footnote, Table 3.5) and although the sample was filtered prior to extraction, it is likely that some of these solids passed the Whatman #1 qualitative filter. At the end of the extraction process, a noticeable film of sediment had settled out on the CH_2Cl_2-water interface. The PNA's detected are therefore thought to have been associated with the solid fraction of the aqueous sample and not dissolved in the water itself. UVALP-3s (Table 3.5), the solid fraction from UVALP-3, was contaminated with acenaphthylene, acenaphthene, and fluorene whereas UVAPZ-4 was not contaminated with

PNA's.

All sediment samples gathered from the southeast quadrant of the site (S-1, S-2, S-3; Table 3.4) and those collected from the flood plain of the North Branch of Hipps Creek were free of contamination by PNA's.

Lake sediment samples, however, contained elevated levels of both PNA's and TEH. In the preliminary draft, ESI documented two major oil spills into Hipps Pond. The first occurred in April 1977 when 240,000 gallons of number one fuel oil (home heating oil) were spilled. Oil recovery operations were immediately implemented and approximately 200,000 gallons were eventually recovered. In April 1978 an unknown volume of Number 6 (heavy black) fuel oil was spilled into Hipps Pond and allowed to remain in the pond for up to five months. Although oil recovery was hampered by leaves and other debris, approximately 44,000 gallons were eventually recovered from the pond. Given this history of the pond, the analytical results of the pond sediments are not surprising.

In summary, the waters of the North and South Branches of Hipps Creek, Hipps Pond, and the outflow stream from Hipps Pond are not found to be contaminated with PNA'S. The only sediments which were found to be contaminated with PNA's were those collected from Hipps Pond. It is believed that this contamination is the result of the documented oil spills and not the result of import from Hipps Creek.

IIIE. Summary

The major points for summary from our study of the organic contamination at the Cheatham Annex site follow.

1) There is not much organic contamination present at Cheatham Annex except in the sediments of Hipps Pond. This contamination may be due to oil spills in 1977 and 1978. It is possible that additional contamination may be trapped by the sediments following high discharge events into the Pond.

Table 3.1. Information on the nature of the samples collected for organic analysis. Sampling locations are indicated on Figure 3.1.

ID	Date	Location
Hipps Pond Surface Water		
LW-1	8/2	Hipps Pond, 7 m from inflow
LW-1r	8/2	
LW-2	8/2	Hipps Pond, mid-pond (Trans 18)
LW-2r	8/2	
Sediments		
S-1	9/3	perimeter north of Diesel Dr.
S-2	9/3	perimeter south of Diesel Dr.
S-3	9/3	perimeter downgradient of cosmoline dump
S-4	8/2	Hipps Pond, 7 m from inflow
S-5	8/2	Hipps Pond, mid-pond
S-6	8/2	Hipps Pond, pond margin
S-7	8/2	North Branch floodplain, at NW-14
S-7r	8/2	
Surface Water		
SW-5	8/2	North Branch, before confluence with South Branch
SW-5	9/3	
SW-6	8/2	South Branch, before confluence with North Branch
SW-6	9/3	
SW-8	8/2	
SW-8	9/3	
SW-9	9/3	perimeter north of Diesel Dr.
SW-10	9/3	perimeter south of Diesel Dr.
SW-11	9/3	perimeter downgradient of cosmoline dump
SW-12	8/2	swampy inflow to Hipps Pond
Groundwater		
UVALP-3	10/9	pondside, downgradient of oil/water separator #2
UVAPZ-4	10/9	upgradient of swampy inflow to Hipps Pond
Suspended Solids		
UVALP-3s	10/9	pondside, downgradient of oil/water separator #2
UVAPZ-4s	10/9	upgradient of swampy inflow to Hipps Pond

Key to meaning of sample names:

"S" = sediment/soil sample
"LW" = pond water sample
"SW" = surface water sample
"LP" = groundwater sample from lake piezometer
"PZ" = groundwater sample from piezometer
"r" = replicate
"s" = solids which were filtered from the water sample

Table 3.2. Polynuclear aromatic hydrocarbons for which analyses were conducted for water and sediment samples from Cheatham Annex.

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Chrysene
Dibenzo(a,h)anthracene
Fluoranthene
Fluorene
Indeno(1,2,3-c,d)pyrene
Naphthalene
Phenanthrene
Pyrene

Table 3.3. Results for organic analyses of Cheatham Annex sediment samples.

	S-4	S-5	S-6	S-7
Naphthalene	<34.48	<44.16	21.03 (1.02)	<14.46
Acenaphthylene	78.22 (4.29)	86.11 (0.44)	48.01 (4.93)	<26.19
Acenaphthene	40.93 (0.62)	45.19 (0.25)	27.56 (5.40)	13.44[a]
Fluorene	16.56 (5.08)	16.54[a]	<3.54	<3.06
Phenanthrene	5.56 (1.73)	6.99 (1.57)	2.80 (0.01)	<1.64
Anthracene	10.08 (0.93)	12.21[a]	<2.25	<1.80
Σ PNA's	151.53	167.04	99.4	13.44
TEH	4,094	9,914	10,317	***[b]

Concentrations of polynuclear aromatic hydrocarbons (PNA's) reported as μg/g dry weight of sediment extracted. Numbers reported represent the mean (standard deviation) of three replicate injections, except where noted.

TEH = total extractable hydrocarbons; determined gravimetrically and reported as μg/gdw sediment.

[a] = compound detected in one chromatogram.

[b] = final weight less than initial weight.

< = indicates the compound was not detected at the given minimum detection quantity.

Table 3.4. Results of organic analyses of Cheatham Annex sediment samples.

	S-1	S-2	S-3	S-7r
Naphthalene	<12.75	<4.94	<4.90	<6.42
Acenaphthylene	<23.10	<8.96	<8.88	<11.62
Acenaphthene	<11.83	<4.59	<4.59	<5.95
Fluorene	<2.70	<1.05	<1.04	<1.36
Phenanthrene	<1.44	<0.56	<0.55	<0.73
Anthracene	<1.58	<0.61	<0.61	<0.80
Σ PNA's	---	---	---	---
TEH	617	515	313	474

Concentrations of Polynuclear Aromatic Hydrocarbons (PNA's) reported as μg/g dry weight of sediment extracted. Numbers reported represent the mean (standard deviation) of three replicate injections, except where noted.

TEH = total extractable hydrocarbons; determined gravimetrically and reported as μg/gdw sediment.

< = indicates the compound was not detected at the given minimum detection quantity.

Table 3.5. Results of organic analyses of Cheatham Annex solid fraction filtered from water samples.

	UVAPZ-4s	UVALP-3s
Naphthalene	<74.22	<10.44
Acenaphthylene	<134.47	23.16 (6.23)
Acenaphthene	<68.86	14.49 (6.90)
Fluorene	<15.73	6.96 (7.06)
Phenanthrene	<8.40	1.58[a]
Anthracene	<9.22	<1.30
Σ PNA's	---	46.19
TEH	2,186	2,837

Concentrations of Polynuclear Aromatic Hydrocarbons (PNA's) reported as μg/g dry weight of sediment extracted. Numbers reported represent the mean (standard deviation) of three replicate injections, except where noted.

TEH = total extractable hydrocarbons; determined gravimetrically and reported as μg/gdw sediment.

[a] = compound detected in one chromatogram.

UVAPZ-4s and UVALP-3s represent the solid fractions of water samples UVAPZ-4 and UVALP-3, respectively, which were retained on Whatman #1 qualitative filters.

Sample	Volume filtered (mL)	Mass retained on filter (g)
UVAPZ-4	1150	1.56
UVALP-3	410	13.30

< = indicates the compound was not detected at the given minimum detection quantity.

Table 3.6. Results of organic analyses of Cheatham Annex water samples.

	SW-8(8/2)	SW-12	SW-6(8/2)	SW-5(8/2)
Naphthalene	<0.24	<0.33	<0.26	<0.26
Acenaphthylene	<0.43	<0.59	<0.47	<0.48
Fluorene	<0.05	<0.07	<0.06	<0.06
Phenanthrene	<0.03	<0.04	<0.03	<0.03
Anthracene	<0.03	<0.04	<0.03	<0.03
Fluoranthene	<0.03	<0.04	<0.03	<0.03
Pyrene	<0.02	<0.02	<0.02	<0.02
Benzo(a)Anthracene	<0.05	<0.07	<0.06	<0.06
Chrysene	<0.06	<0.09	<0.07	<0.07
Benzo(b)Fluoranthene	<0.14	<0.19	<0.15	<0.15
Benzo(k)Fluoranthene	<0.13	<0.18	<0.15	<0.15
Benzo(a)Pyrene	<0.10	<0.14	<0.11	<0.11
Indeno(1,2,3-c,d)Pyrene	<0.13	<0.17	<0.14	<0.14
DiBenzo(a,h)Anthracene	<0.28	<0.38	<0.30	<0.31
Σ PNA's	---	---	---	---
TEH	2.45	0.28	2.92	1.70

All concentrations reported as μg/mL. Figures reported are the mean (standard deviation) of three replicate injections except where indicated.

TEH = total extractable hydrocarbons; determined gravimetrically and reported as μg/mL.

< = indicates the compound was not detected at the given minimum detection quantity.

Table 3.7. Results of organic analyses of Cheatham Annex water samples.

	SW-5(9/3)	SW/6(9/3)	SW-8(9/3)	SW-9
Naphthalene	<0.13	0.25[a]	<0.14	<0.16
Acenaphthylene	<0.24	<0.31	<0.25	<0.29
Fluorene	<0.03	<0.04	<0.03	<0.03
Phenanthrene	<0.02	<0.02	<0.02	<0.02
Anthracene	<0.02	<0.02	<0.02	<0.02
Fluoranthene	<0.02	<0.02	<0.02	<0.02
Pyrene	<0.01	<0.01	<0.01	<0.01
Benzo(a)Anthracene	<0.03	<0.04	<0.03	<0.04
Chrysene	<0.04	<0.05	<0.04	<0.04
Benzo(b)Fluoranthene	<0.08	<0.10	<0.08	<0.09
Benzo(k)Fluoranthene	<0.07	<0.10	<0.08	<0.09
Benzo(a)Pyrene	<0.06	<0.07	<0.06	<0.07
Indeno(1,2,3-c,d)Pyrene	<0.07	<0.09	<0.07	<0.09
DiBenzo(a,h)Anthracene	<0.16	<0.20	<0.16	<0.19
Σ PNA's	---	0.25	---	---
TEH	0.11	1.50	1.13	0.83

All concentrations reported as μg/mL. Figures reported are the mean (standard deviation) of three replicate injections except where indicated.

TEH = total extractable hydrocarbons; determined gravimetrically and reported as μg/mL.

[a] = compound detected in only one chromatogram

< = indicates the compound was not detected at the given minimum detection quantity.

Table 3.8. Results of organic analyses of Cheatham Annex water samples.

	SW-10	SW-11[b]	LW-1+LW-1r[b]	LW-2+LW-2r
Naphthalene	0.37[a]	0.19	0.23	0.16 (0.00)
Acenaphthylene	0.47 (0.04)	0.39	0.51	<0.28
Fluorene	0.17[a]	0.08	<0.03	<0.03
Phenanthrene	0.11 (0.06)	0.09	0.11	<0.02
Anthracene	0.3[a]	0.07	0.06	<0.02
Fluoranthene	0.16 (0.05)	0.3	0.34	<0.02
Pyrene	0.48[a]	0.18	0.12	<0.01
Benzo(a)Anthracene	0.16 (0.10)	0.52	0.05	<0.04
Chrysene	0.32[a]	0.22	<0.04	<0.04
Benzo(b)Fluoranthene	<0.14	0.08	<0.08	<0.09
Benzo(k)Fluoranthene	<0.13	0.09	<0.08	<0.09
Benzo(a)Pyrene	<0.10	0.06	<0.06	<0.07
Indeno(1,2,3-c,d)Pyrene	0.17 (0.06)	0.18	<0.07	<0.08
DiBenzo(a,h)Anthracene	0.34 (0.08)	<0.16	<0.16	<0.18
Σ PNA's	1.88 (0.99)	2.45	1.42	0.16
TEH	0.10	0.29	1.41	2.22

All concentrations reported as μg/mL. Figures reported are the mean (standard deviation) of three replicate injections except where indicated.

TEH = total extractable hydrocarbons; determined gravimetrically and reported as μg/mL.

[a] = compound detected in only one chromatogram.

[b] = all compounds reported were detected in the same single chromatogram and were not detected in the two other replicate injections.

< = indicates the compound was not detected at the given minimum detection quantity.

Table 3.9. Results of organic analyses of Cheatham Annex water samples.

	UVAPZ-4	UVALP-3
Naphthalene	<0.15	0.37 (0.01)
Acenaphthylene	<0.27	0.52 (0.01)
Fluorene	<0.03	<0.06
Phenanthrene	<0.02	<0.03
Anthracene	<0.02	<0.04
Fluoranthene	<0.02	<0.04
Pyrene	<0.01	<0.02
Benzo(a)Anthracene	<0.03	<0.06
Chrysene	<0.04	<0.08
Benzo(b)Fluoranthene	<0.09	<0.17
Benzo(k)Fluoranthene	<0.08	<0.16
Benzo(a)Pyrene	<0.06	<0.12
Indeno(1,2,3-c,d)Pyrene	<0.08	<0.15
DiBenzo(a,h)Anthracene	<0.17	<0.33
Σ PNA's	---	0.89
TEH	2.06	4.63

All concentrations reported as μg/mL. Figures reported are the mean (standard deviation) of three replicate injections except where indicated.

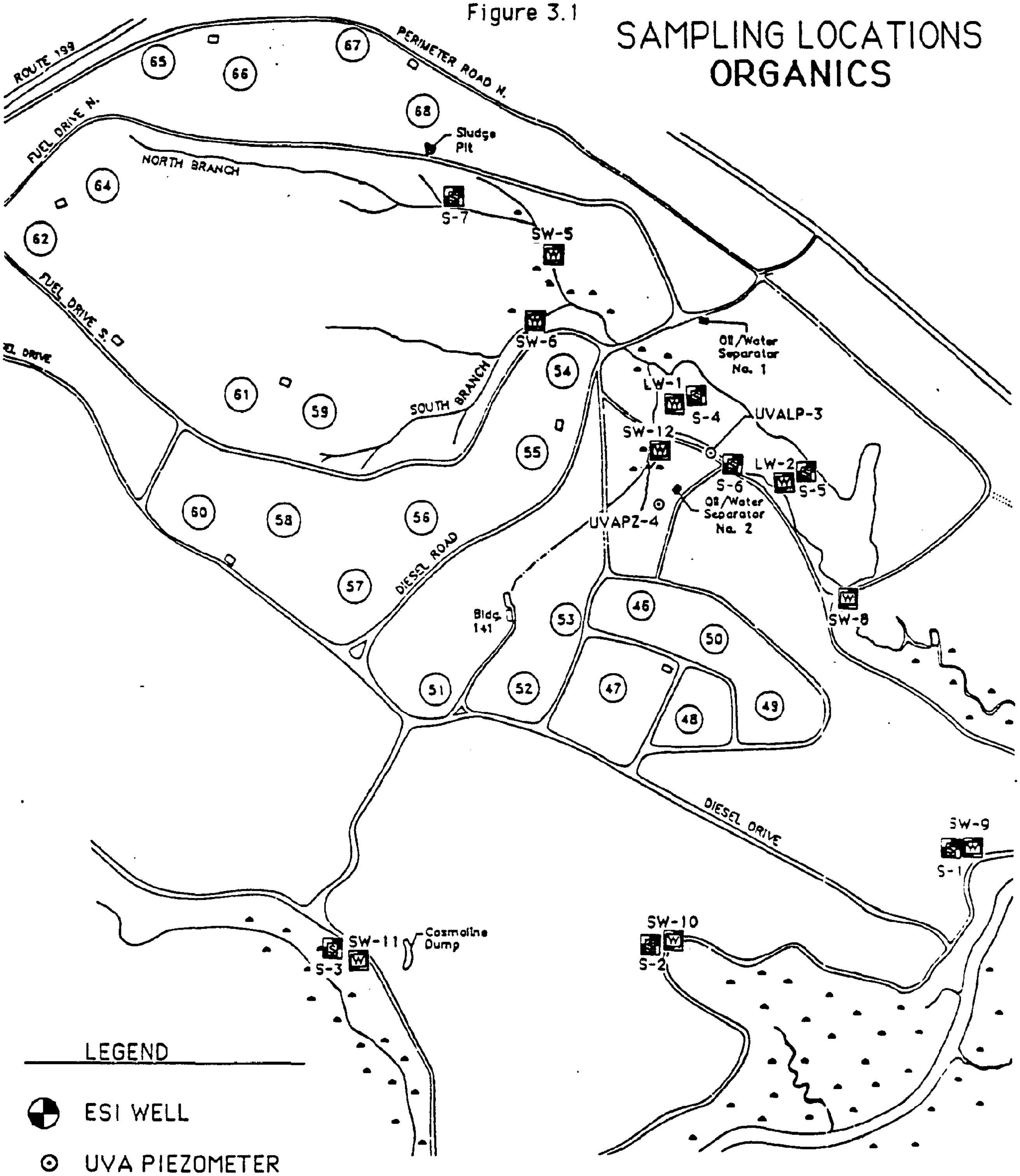
TEH = total extractable hydrocarbons; determined gravimetrically and reported as μg/mL.

Water samples UVAPZ-4 and UVALP-3 were filtered through Whatman #1 qualitative filters. The aqueous filtrates retained these sample IDs and received treatment similar to all other water samples. The solids retained by the filter were designated UVAPZ-4s and UVALP-3s, respectively, and received treatment similar to all other sediment samples.

< = indicates the compound was not detected at the given minimum detection quantity.

Figure 3.1

SAMPLING LOCATIONS ORGANICS



(Taken from: ESI, 1989)

CHEATHAM ANNEX PROJECT
Department of Environmental Sciences
University of Virginia
December 1, 1990

IV. METALS

IVA. Introduction

It has been shown that the Cheatham Annex site is contaminated by inorganic substances as well as organic substances. Previous chemical analyses performed on the Cheatham Annex site indicate the presence of metal contamination (ESI, 1989). ESI's analyses of soil borings and surface water samples revealed very little inorganic contamination. They detected heavy metal contamination above background levels, however, in 4 out of 8 sediment samples collected at the surface water sites and in most (10 out of 16) of their groundwater samples (Table 4.1). Particularly, ESI measured concentrations above the current groundwater maximum contamination limit (MCL) as didctated by EPA for arsenic, cadmium, chromium, and lead in many of their groundwater samples.

Four regions of concern can be isolated from the ESI report. The highest recorded levels of metals contamination were present in the groundwater samples collected from the berm at the northern (inflow) end of Hipps Pond. The samples were taken near an oil/water separator located in the berm. Another area of high metals concentration was located around the other oil/water separator on the southern side of the pond. A third region of groundwater contamination is located near the sludge pit alongside the North Branch of Hipps Creek. Finally, metals were also detected at locations in the upper portion of the South Branch of Hipps Creek.

We chose our sampling sites based on these previous findings and proximity to our hydrologic studies. We monitored those wells from which ESI had measured particularly high metals concentrations the previous year in order to evaluate any changes. We also installed new wells and sampled new surface water locations which gave us a more in-depth chemical characterization of specific areas of concern on the site.

IVB. Methods

Sampling Philosophy

We chose to concentrate our sample collection sites for metals over three regions of investigation. Focusing on the area of the North Branch of Hipps Creek, we sampled surface water, groundwater, and sediments (Fig. 4.2). We also sampled surface and groundwater entering Hipps Pond, surface water and sediments in the pond itself, and surface-water outflow from the pond (Fig. 4.1). The third region of sampling was on the southern side of the pond where various groundwater samples were collected. The nature and location of all samples collected for metals analysis are summarized in Table 4.2. All samples are described in Appendix I.

Sampling locations along the North Branch were chosen to give us a more comprehensive understanding of the contamination of different media in this area. Previous analyses by ESI indicated high concentrations of metals in the groundwater below sludge pit #1. In particular, we hoped to characterize a plume of contamination which may be extending from the dumping area towards the stream. Sediments and groundwater downgradient of this pit were collected as well as surface water samples in the North Branch. Groundwater was collected from monitoring well MW-7 which had been installed and monitored by ESI in 1989. Two additional wells were installed and monitored at the margin of the floodplain and on the floodplain. One sediment sample was collected on the floodplain. Surface samples were taken at five points along the stream both upstream and downstream of the sludge pit.

Sampling locations in the vicinity of Hipps Pond were chosen to monitor and further characterize the contamination of the pond and to attempt to locate any possible point sources of contamination. In previous work by ESI, the highest levels of metal contamination were found in a deep well installed next to an oil water separator in the man-made berm at the northern edge of the pond near the inflow. Samples of all types and media were collected in and around Hipps Pond. Groundwater and surface water inflow locations were sampled at various points along the pond margin. Groundwater samples were collected from MW-5, the monitoring well which had such high levels of contamination reported by ESI. This well is located very close to the inflow culvert from the North and South Branch streams. A surface water sample was collected before the stream entered the berm, and another as the stream emerged in Hipps Pond on the other side. Groundwater samples were also collected from a lakeside piezometer located downgradient of the other oil water separator to further monitor groudwater inflow to the pond. Surface and sediment samples were also collected from the pond itself. We sampled both the shallower inflow end of the pond as well as the sediments and surface water of the deeper, mid-pond region. We also sampled sediments on the pond margin near our groundwater collection sites on the south side. We monitored the surface water outflow from the pond.

The final region of investigation was the area surrounding the other oil water separator located on the south side of the pond. As in the previous regions of study, we were interested in more specific information on the chemical composition of the water in this area than had previously been available. Groundwater samples were collected at MW-6, a monitoring well from which ESI had also collected samples and recorded high levels of metals. Another groundwater sample was collected downgradient of the pit closer to the pond margin.

Collection of Samples for Metals Analysis

Water Samples

The surface water samples were collected by submerging sampling jars 1-5 cm below the surface. The jars were filled completely so no head space remained. All water samples collected for heavy metal analysis were stored in 0.5 L teflon coated clear glass jars sealed with aluminum foil and screw tops. The samples were placed in an ice-filled cooler and later stored under refrigeration prior to analysis. During the sampling procedure ubber gloves were worn at all times.

The pond water sample was collected before the sediment samples in each location were collected. This prevented contamination of the water sample by agitated bottom sediments.

Groundwater samples were collected from wells installed at least three weeks previous to the collection date (see section IIC of this report for well installation details). A minimum of three well volumes of water were evacuated from each well prior to sampling. Most samples were collected using a stainless steel WILCO sampler which was rinsed with deionized water before each sample was collected. Sample LP-5 was collected from a one inch piezometer which was too small for the Wilco sampling device; this sample was collected using a Nalgene hand pump fitted with Tygon tubing. Sample jars were filled as completely as possible.

Sediment Samples

The pond sediment samples were collected using a steel Wilco sediment bucket sampler. Samples were collected to a depth of 10 cm below the sediment-water interface. During sampling rubber gloves were worn at all times. The bucket was rinsed after each sample was collected.

The pondside sediment sample was collected using a hand auger which collected to a depth of 15 cm. The North Branch floodplain sediment sample was collected using a shovel to a depth of 5 cm.

All sediment samples were placed in sealable plastic bags from which as much air as possible was removed. The samples were placed in a cooler filled with ice and frozen immediately upon return to the lab.

Analysis

The water samples and the sediment samples were submitted for analysis to Mike Lockhart at Havens Laboratory in Charlottesville, VA. The water samples were analyzed for six metals: chromium, silver, cadmium, barium, mercury, and lead. Contrary to our request the report from Havens Laboratory did not include results from arsenic analysis. No analyses of the sediment samples were returned to us. No information on the methods of chemical analysis or of sample treatment prior to analysis was made available to us.

IVC. Results

The results of the chemical analysis are listed in Table 4.3. The concentrations of four of the six metals, silver, cadmium, mercury, and lead, were below the detection limit of analysis in all water samples. For simplification we have listed a summary of the detected metals concentrations in Table 4.4.

Detectable chromium concentrations ranged from 0.011 mg/L to 0.014 mg/L and were found in both groundwater and suface water samples. All of the measured concentrations were less than the maximum contamination limit set by EPA of 0.04 mg/L. The highest chromium concentrations were found in groundwater samples ESIMW-5 and UVANW-14. There does not seem to be any identifiable areas of the site represented by the samples with detected concentration levels as these samples are located in nearly every sampling region.

Detectable barium concentrations ranged from 0.31 mg/L to 0.34 mg/l and were found in only three locations: the surface water of Hipps Pond collected at mid-pond and groundwater sampling locations UVALP-5 and ESIMW-5. The highest concentrations were found in ESIMW-5. None of these concentration values were higher than the maximum concentration limit set by the EPA of 5 mg/L.

We reported detectable levels of both barium and chromium in one groundwater location, ESIMW-5. This well is located on the inflow berm of Hipps Pond near an oil/water separator.

IVD. Discussion

The concentration of metals in the groundwater samples collected in the present investigation was very low (Tables 4.3 and 4.4). Our results indicate that there is no significant metals contamination in the areas we sampled. This finding is in dramatic contrast to the results reported by ESI in 1989 (Table 4.1).

We are uncertain what these results mean. It seems unlikely that there would be such a large reduction in these metal concentrations in one year. Having only one suite of samples from each study, though, does not allow us to evaluate whether present or antecedent hydrologic conditions influence the concentrations we observe. Several observations need to made over time in order to evaluate the reality of metals contamination at this site.

We do not have adequate information on sample collection, treatment, preservation, and analysis methods employed in the two studies to even feel confident that either group has reported real values of dissolved metals concentrations in the groundwater at the Cheatham Annex site.

ESI (1989) did not filter their groundwater samples before acidification. Thus dissolution of any suspended particles in the groundwater (clay, silt-sized grains, etc.) would have contributed to the metals concentrations determined in the laboratory. We would expect that the solid phase would be relatively concentrated in metals relative to the aqueous phase, and the acid dissolution of a small mass of suspended material could make a significant contribution to the analyzed metal concentration. Our experience in collecting groundwater at the site is that it appears turbid upon collection and these suspended sediments settle out of the sample as it sits in the sample bottle.

Water Samples for this report were collected under the supervision of Mike Lockhart. Groundwater samples were collected, stored in bottles, and kept on ice. They were not filtered; they were not acidified in the field. Havens laboratory was unavailable to comment on whether the samples were filtered or acidified after return to the laboratory. It is also not clear how long the samples were stored prior to analysis.

Analysis of trace metals requires not only careful analytical work, but special precautions taken in the collection, preservation, and storage of samples. The Environmental Protection Agency, the American Public Health Association, and the U.S. Geological Survey, to mention a few, have published recommended guidelines for such work. Some common recommendations include immediate filtering and acidification of water samples upon collection. These steps must be taken before change in pH or oxidation state of the sample itself, usually through exposure to the atmosphere, cause changes in the saturation state of the water. Any dissolution of solid phase before the solution is preserved would result in a misrepresentation of *in situ* groundwater composition by analytical methods. In situ metals composition would also be misrepresented if precipitation from the sample occurred without subsequent acidification. Adequate care was simply not taken in the previous or the present study of the groundwater Cheatham Annex. The magnitude and extent of metals contamination of the subsurface water at this site are simply not known.

IVE. Summary

The major points for summary from our study of the metals contamination of the Cheatham Annex site follow.

1) Because of deficiencies in the studies to date, the extent and magnitude of metals contamination is unknown.

Table 4.1. Summary of metals analyses reported by ESI (1989). All concentrations are expressed in mg/L. Listed are groundwater samples with metal concentrations which exceed both the maximum contamination limit (MCL) and background concentration (MW-1).

Well	Cr	Cd	As	Pb	Description
MW-2	0.16	---	---	---	alongside North Branch, upstream of sludge pit
MW-5	1.51	0.077	0.91	0.41	inflow berm to Hipps Pond at oil/water separator #1
rep.	1.29	0.075	0.92	0.37	
MW-6	0.30	0.021	0.101	0.07	south of Hipps Pond, near oil/water separator #2
MW-7	0.10	---	0.10	---	alongside North Branch, below sludge pit
MW-9	0.25	---	0.16	---	near swamply inflow to Hipps Pond
MW-10	0.27	---	0.12	---	uphill of inflow berm to Hipps Pond
MW-12	0.13	---	0.07	---	inflow berm to Hipps Pond
MW-13	0.20	---	0.12	---	south of Hipps Pond, at oil/water separator
PZ-1	0.10	---	0.10	---	South Branch, far upstream
PZ-4	0.31	---	0.16	---	South Branch, far upstream
MCL[a]	0.05	0.01	0.05	0.05	
MW-1[b]	0.09	---	0.04	---	north of Perimeter Road North

[a] = current groundwater maximum contamination limit (MCL) dictated by EPA.

[b] = groundwater collected away from sites of known contamination; taken to be representative of background groundwater composition

Table 4.2. Information on the nature of the samples collected for metals analyses.

ID	Date	Figure #	Location
Hipps Pond Surface Water			
LW-2	7/31	4.1	Hipps Pond, mid-pond
LW-3	7/2	4.1	Hipps Pond, at inflow culvert
LW-3r	7/24	4.1	
Surface Water			
SW-1	7/24	4.2	North Branch, at NW-12 (station 4a)
SW-2	7/24	4.2	North Branch, below NW-13 (station 8a)
SW-3	7/24	4.2	North Branch, across from NW-15 (station 10a)
SW-3r	7/24	4.2	
SW-4	7/24	4.2	North Branch, downstream of NW-15
SW-5	7/24	4.2	North Branch, before confluence with South Branch
SW-7	7/24	4.1	Hipps Creek, just before culvert
SW-8	7/24	4.1	Hipps Pond, outflow before flume
Groundwater			
UVALP-5	7/31	4.1	pondside, downgradient of oil/water separator #2
ESIMW-5	7/24	4.1	inflow berm to Hipps Pond at oil/water separator #1
ESIMW-5r	7/24	4.1	
ESIMW-5	7/31	4.1	
ESIMW-5r	7/31	4.1	
ESIMW-6	7/31	4.1	south of Hipps Pond, near oil/water separator #2
ESIMW-6r	7/31	4.1	
ESIMW-7	7/24	4.2	alongside North Branch, below sludge pit
ESIMW-7r	7/24	4.2	
UVANW-14	7/31	4.2	perimeter North Branch floodplain below sludge pit
UVANW-15	7/31	4.2	North Branch floodplain, below sludge pit
ESIPZ-2	7/31	4.1	downgradient of oil/water separator #2

Key to meaning of sample names:

"S" = sediment/soil sample
"LW" = pond water sample
"SW" = surface water sample
"LP" = groundwater sample from lake piezometer
"PZ" = groundwater sample from piezometer
"MW" or "NW" = groundwater sample from monitoring well
"r" = replicate

Table 4.3. Results of metals analyses. All concentrations are expressed as mg/L.

ID	Sampling Date	Cr	Ag	Cd	Ba	Hg	Pb
SW-1	7/24	0.011	<0.02	<0.003	<0.3	<0.0002	<0.01
SW-2	7/24	0.011	<0.02	<0.003	<0.3	<0.0002	<0.01
SW-3	7/24	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01
SW-3r	7/24	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01
SW-4	7/24	0.011	<0.02	<0.003	<0.3	<0.0002	<0.01
SW-5[a]	7/24						
SW-7	7/24	0.012	<0.02	<0.003	<0.3	<0.0002	<0.01
SW-8	7/24	0.011	<0.02	<0.003	<0.3	<0.0002	<0.01
LW-2	7/31	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01
LW-3	7/24	0.012	<0.02	<0.003	<0.3	<0.0002	<0.01
LW-3r	7/24	<0.01	<0.02	<0.003	0.32	<0.0002	<0.01
ESIMW-5	7/24	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01
ESIMW-5r	7/24	<0.01	<0.02	<0.003	0.31	<0.0002	<0.01
ESIMW-5	7/31	0.014	<0.02	<0.003	0.32	<0.0002	<0.01
ESIMW-5r	7/31	0.012	<0.02	<0.003	0.34	<0.0002	<0.01
ESIMW-6	7/31	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01
ESIMW-6r	7/31	0.011	<0.02	<0.003	<0.3	<0.0002	<0.01
ESIMW-7	7/24	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01
ESIMW-7r	7/24	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01
ESIPZ-2	7/31	0.011	<0.02	<0.003	<0.3	<0.0002	<0.01
UVALP-5	7/31	<0.01	<0.02	<0.003	0.32	<0.0002	<0.01
UVANW-14	7/31	0.014	<0.02	<0.003	<0.3	<0.0002	<0.01
UVANW-15	7/31	<0.01	<0.02	<0.003	<0.3	<0.0002	<0.01

[a] = insufficient sample to analyze

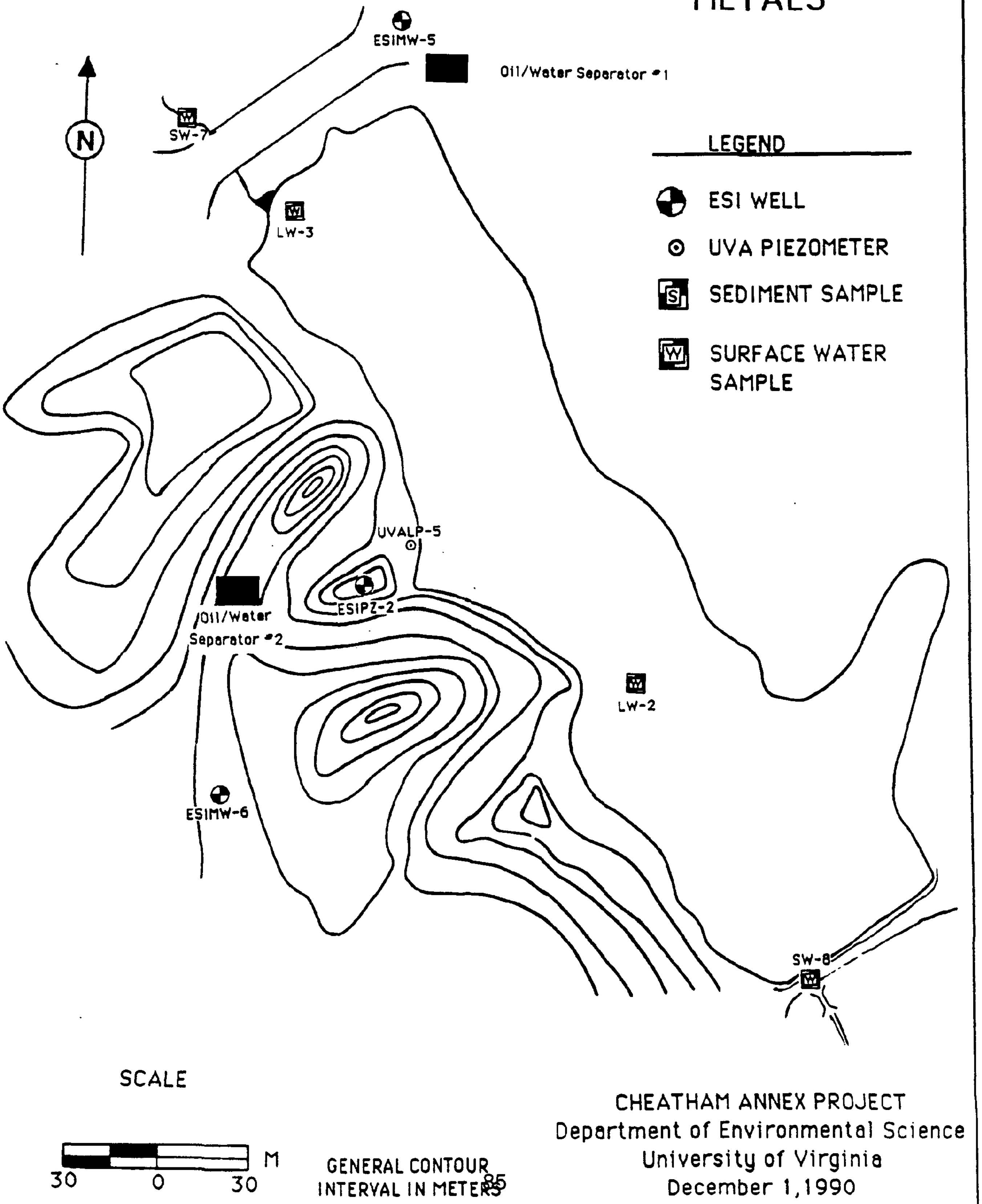
Table 4.4. Summary of detected metals. Concentrations are expressed as mg/L.

	Cr	Ba	Description
SW-1	0.011	---	North Branch, at NW-12 (station 4a)
SW-2	0.011	---	North Branch, below NW-13 (station 8a)
SW-4	0.011	---	North Branch, downstream of NW-15
SW-7	0.012	---	Hipps Creek, just before culvert
SW-8	0.011	---	Hipps Pond, outflow before flume
LW-3r	---	0.32	Hipps Pond, at inflow culvert
ESIMW-5r(7/24)	---	0.31	inflow berm to Hipps Pond at oil/water separator
ESIMW-5(7/31)	0.014	0.32	
ESIMW-5r(7/31)	0.012	0.34	
ESIMW-6r	0.011	---	south of Hipps Pond, aside sludge pit #2
ESIPZ-2	0.011	---	downgradient of sludge pit #2 and oil/water seporator
UVANW-14	0.014	---	perimeter of North Branch floodplain below sludge pit #1
UVALP-5	---	0.32	pondside, downgradient of sludge pit #2 and oil/water separator
Detection Limit	0.01	0.3	

--- = below detection limit

Figure 4.1

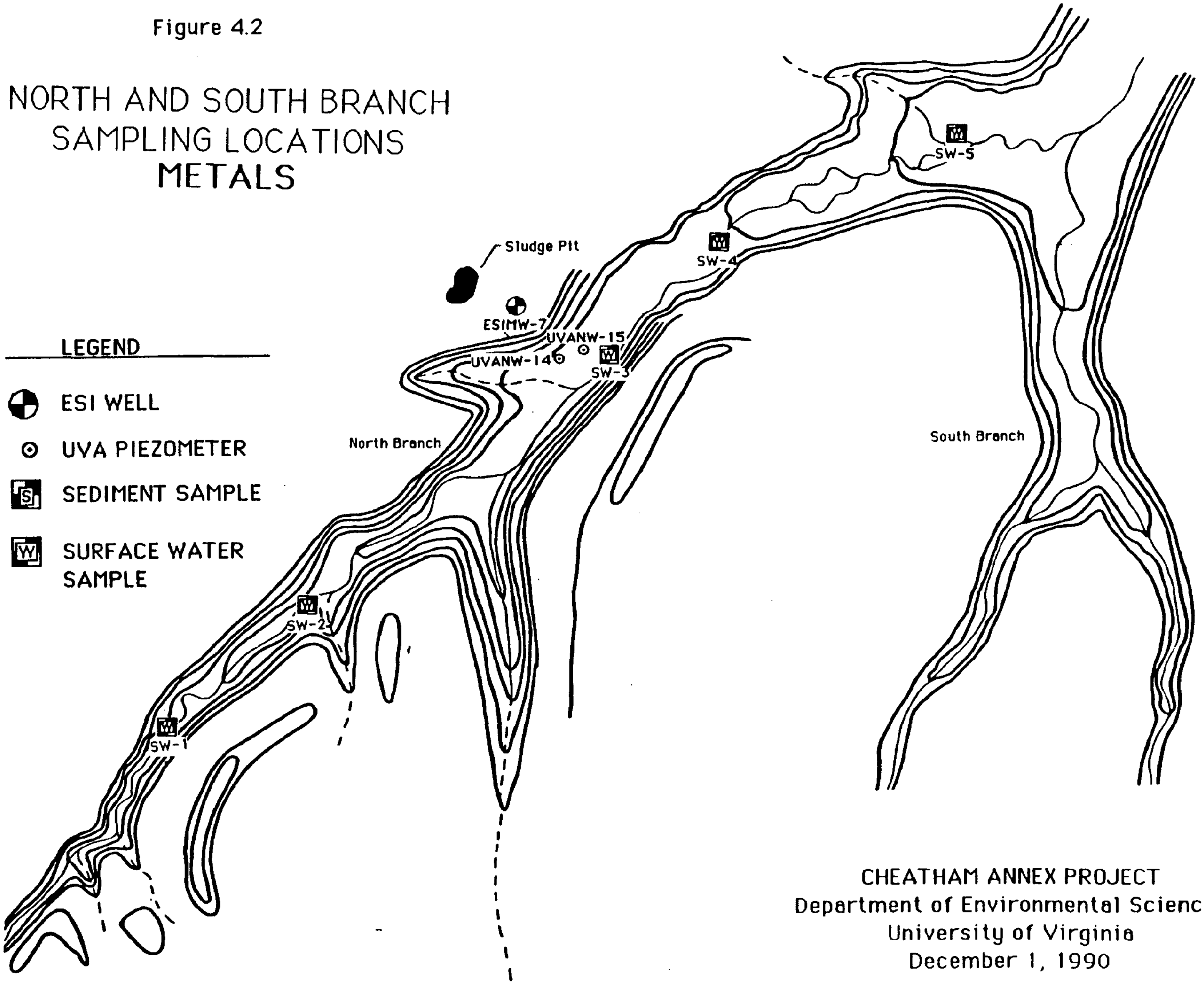
HIPPS POND
SAMPLING LOCATIONS
METALS



CHEATHAM ANNEX PROJECT
Department of Environmental Science
University of Virginia
December 1, 1990

Figure 4.2

NORTH AND SOUTH BRANCH
SAMPLING LOCATIONS
METALS



CHEATHAM ANNEX PROJECT
Department of Environmental Sciences
University of Virginia
December 1, 1990

V. DISCUSSION

The primary objective of our research at Cheatham Annex was to identify the major components driving the hydrology of the site, and characterize the organic and heavy metal contamination in the areas most strongly affected by hydrological forces. Based on the results of our chemical analyses, significant organic contamination was not found in the surface waters of the site, nor in two groundwater samples from the south side of the pond. We cannot make any conclusions about heavy metal contamination due to possible laboratory errors. Nevertheless, the organic data provide an indicator of the water quality status in hydrologically critical areas at the site.

Our conclusions from the hydrological research at the site demonstrated the dominance of base-flow surface water on the overall site water budget through Hipps Pond. These inputs are derived from the entire site area and are continually delivered to the Pond at all times. It is likely that base-flow chemistry, with regards to organic contamination, would not significantly differ over the course of several seasons. The factors affecting the magnitude of surface water input are mainly PET in the hillslope soils and recharge to the creek contributing areas. Although base-flow rates will fluctuate seasonally, considerable changes in the nature of the waters would not be expected.

These inferences allow the results of the organic analyses to be cast into a broader framework. It is likely that base flows into Hipps Pond will continue to be dilute with respect to organics through the seasons. As base flow drops and portions of each creek from the headwater areas towards downstream cease to flow, the relative input from drainage areas containing storage tanks changes, but analyses of groundwater samples indicate that large changes in PNA concentrations in the stream are unlikely.

Generally, all tanks are located in the headwater regions of the creeks, and also line one side along the creeks' lengths (Figure 2.1). Contributions from the headwater areas are greatest during the high base-flow periods of the early summer. We did not observe any systematic change in organic concentrations over the course of the field season, suggesting that the contributions of potentially contaminated inflow areas does not change over time.

However, these results can not be extrapolated through time because of the potential influence of radically changed flow conditions during spring high-flow conditions. Furthermore, contaminants in the groundwater may move very slowly because of the flat gradients. Thus, it is possible that some plume of contamination, which our survey did not identify, may break through and contaminate surface waters. For example, several "hot spots" of organic contaminants have been identified (ESI, 1989), but no data are available about the lateral or vertical extent of contaminants. A more complete characterization of the spatial distribution of contaminants, the groundwater flow rates, and the adsorption properties of the soils would greatly improve our ability to assess the potential for mobilization and off-site migration of contaminants. Our results can be used only for short time-scale assessment of contaminant migration during base-flow conditions.

These observations do not imply that contaminants are not present in the areas we sampled. Previous investigations have indicated that sediments in many areas contain disproportionate concentrations of organic compounds relative to the water with which they are in contact (ESI, 1989). It is likely that chemical factors govern the movement of the contaminants, and base flow hydrological processes play a secondary role.

The sediment sample collected from the floodplain of the North Branch did not contain significant concentrations of organics. Floodplain sediments and stream channel sediments are the most mobile and unstable materials in a catchment. The areas in which they occur were shown to be the major sources of response water during storms. Due to the interplay between chemical, hydrological, and geomorphological processess, the single sediment sample may not necessarily be "representative" of floodplain sediments in general.

Based on steep near-stream lateral and vertical gradients related to storms, storm flow is predominantly comprised of floodplain and bank water displace during these events. Immobilized contaminants concentrated at the stream margins may enter the stream, resulting in increased migration during storms. Consequently, storm flow, rather than base flow, could potentially carry the bulk of contaminants to Hipps Pond. This conclusion suggests that although base flow is the major hydrological inflow component to Hipps Pond, storm flow might be the most significant component related to contaminant transport to Hipps Pond.

The role of storms in delivering short-lived but high concentration pulses of contaminants to the pond is a possibility that clearly warrents further consideration. We were unable to collect pond or creek surface water samples during or following large storms. Field observations following storm events indicated however, that significant amounts of sediment are moved downchannel, and considerable scour occurs in the bottom of Hipps pond. Organic compounds with low aqueous solubilities may tend to move with sediment particles during storm events. These sediments could be drawn from along the entire reach of the creeks. Upon reaching the pond, sediments, and the associated organics, would settle out.

Overall, our investigation of the contamination of the surface and near surface waters indicates that generally concentrations of organics are low under base flow conditions. Over the seasonal cycle, surface water concentrations would not be expected to change considerably. To extend our base-flow observations to a larger time-scale, further investigations should be undertaken to examine the distribution of contaminants over the entire site, and along flow-paths to the creeks.

VI. CONCLUSIONS AND RECOMMENDATIONS

1) Any soluble subsurface contamination that is mobilized in the vicinity of the storage tanks, the discarded drums, the cosmoline dump, and so forth will move down gradient in the shallow groundwater and flow toward local streams and/or toward King's Creek and the York River.
2) No major areas of contamination, other than sediments of Hipps Pond, were discovered in our study. There is large uncertainty, however, regarding the magnitude and extent of undiscovered contamination of soils and groundwater. There is also great uncertainty regarding the possible fate and transport of any contamination at the Cheatham Annex site.
3) Further work is required to
    a) characterize the inflow and outflow of contaminated water in Hipps Pond during winter and spring high-flow conditions;
    b) accurately determine the magnitude and extent of metals contamination at the site;
    c) assess the extent of the contamination of soils by organic contaminants and characterize the soil/water partitioning of those organics; and
    d) determine the rates of sediments in Hipps Pond and the biodegradation rates of organic contaminants in the sediments.

VII. REFERENCES

Cherry, R.A., 1974. Streamflow generation. Reviews in Geophysics and Space Physics. 12: 627-646.

Engineering-Science, Inc., 1989. Site Investigation Report, Commonwealth of Virginia Emergency Fuel Storage Facility, York County, Virginia. Preliminary draft.

Freeze, R.A. and A. Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, N.J.

Hamon, W.R., 1961. Estimating potential evapotranspiration. Journal of Hydraulics Division of the Proceedings of the American Society of Civil Engineers. 87: 107-210.

Kolla, E., 1987. Estimating storm peaks from small rural catchments in Switzerland. Journal of Hydrology. 95: 203-225.

McIntyre, P.E., 1988. Groundwater Seepage And Sulfur Diagenesis In Acidified Lake Sediments. PhD. dissertation, Department of Environmental Sciences, University of Virginia.

Winter, T.C., 1981. Uncertainties in estimating the water balance of lakes. Water Resources Bulletin. 17: 82-112.

VIII. APPENDICES

Appendix I. Nature of Samples

ID	Date	Anal.	Figure #	Location
Hipps Pond Surface Water				
LW-1	8/2	Org.	3.1	Hipps Pond, 7 m from inflow
LW-1r	8/2	Org.	3.1	
LW-2	7/31	H.M.	4.1	Hipps Pond, mid-pond
LW-2	8/2	Org.	3.1	
LW-2r	8/2	Org.	3.1	
LW-3	7/24	H.M.	4.1	Hipps Pond, at inflow culvert
LW-3r	7/24	H.M.	4.1	
Sediments				
S-1	9/3	Org.	3.1	perimeter north of Diesel Dr.
S-2	9/3	Org.	3.1	perimeter south of Diesel Dr.
S-3	9/3	Org.	3.1	perimeter downgradient of cosmoline dump
S-4	8/2	Org.	3.1	Hipps Pond, 7 m from inflow
S-5	8/2	Org.	3.1	Hipps Pond, mid-pond
S-6	8/2	Org.	3.1	Hipps Pond, pond margin
S-7	8/2	Org.	3.1	North Branch floodplain, at NW-14
S-7r	8/2	Org.	3.1	
Surface Water				
SW-1	7/24	H.M.	4.2	North Branch, at NW-12 (station 4a)
SW-2	7/24	H.M.	4.2	North Branch, below NW-13 (station 8a)
SW-3	7/24	H.M.	4.2	North Branch, across from NW-15 (station 10a)
SW-3r	7/24	H.M.	4.2	
SW-4	7/24	H.M.	4.2	North Branch, downstream of NW-15
SW-5	7/24	H.M.	4.2	North Branch, before confluence with South Branch
SW-5	8/2	Org.	3.1	
SW-5	9/3	Org.	3.1	
SW-6	8/2	Org.	3.1	South Branch, before confluence with North Branch
SW-6	9/3	Org.	3.1	
SW-7	7/24	H.M.	4.1	Hipps Creek, just before culvert
SW-8	7/24	H.M.	4.1	Hipps Pond, outflow before flume
SW-8	8/2	Org.	3.1	
SW-8	9/3	Org.	3.1	
SW-9	9/3	Org.	3.1	perimeter north of Diesel Dr.
SW-10	9/3	Org.	3.1	perimeter south of Diesel Dr.
SW-11	9/3	Org.	3.1	perimeter downgradient of cosmoline dump
SW-12	8/2	Org.	3.1	swampy inflow to Hipps Pond

ID	Date	Anal.	Map ID	Location
Groundwater				
UVALP-3	10/9	Org.	3.1	pondside, downgradient of oil/water separator #2
UVALP-5	7/31	H.M.	4.1	pondside, downgradient of oil/water separator #2
ESIMW-5	7/24	H.M.	4.1	inflow berm to Hipps Pond at oil/water separator #1
ESIMW-5r	7/24	H.M.	4.1	
ESIMW-5	7/31	H.M.	4.1	
ESIMW-5r	7/31	H.M.	4.1	
ESIMW-6	7/31	H.M.	4.1	south of Hipps Pond, near oil/water separator #2
ESIMW-6r	7/31	H.M.	4.1	
ESIMW-7	7/24	H.M.	4.2	alongside North Branch, below sludge pit
ESIMW-7r	7/24	H.M.	4.2	
UVANW-14	7/31	H.M.	4.2	perimeter North Branch floodplain below sludge pit
UVANW-15	7/31	H.M.	4.2	North Branch floodplain, below sludge pit
ESIPZ-2	7/31	H.M.	4.1	downgradient of oil/water separator #2
UVAPZ-4	10/9	Org.	3.1	upgradient of swampy inflow to Hipps Pond
Suspended Solids				
LP-3s	10/9	Org.	3.1	pondside, downgradient of oil/water separator #2
PZ-4s	10/9	Org.	3.1	upgradient of swampy inflow to Hiips Pond

Key to meaning of sample names:

"S"= sediment/soil sample
"LW" = pond water sample
"SW" = surface water sample
"LP" = groundwater sample from lake piezometer
"PZ" = groundwater sample from piezometer
"MW" or "NW" = groundwater sample from monitoring well
"r" = replicate
"s" = solids which were filtered from the water sample

Appendix 2. Water Level Measurements - UVA Wells

Appendix 2. Summary of water level measurements from UVA wells. All values expressed as absolute elevations above mean sea level.

Date UVA well	6/6 current (m)	6/13 current (m)	6/21 current (m)	6/27 current (m)	7/2 current (m)	High (m)
UVANW-11				9.42	9.41	
UVANW-10				9.35	9.23	9.50
UVANW-9		9.62	9.20	9.29	9.29	
UVANW-8		8.85	9.28	9.29	9.29	9.32
UVANW-7		9.34	9.30	9.34	9.33	
UVANW-6		9.28	9.33	9.34	9.19	9.42
UVANW-5	9.75	9.95	9.94	9.87	9.90	
UVANW-4	8.66	8.69	8.67	8.64	8.62	8.58
UVANW-3	9.05	8.96	8.93	8.87	8.97	
UVANW-2	7.71	8.56	8.58	8.56	8.31	8.57
UVANW-1		8.50	8.31	8.33	8.29	
UVAPZ-1	3.81	3.83	3.81	3.82	3.80	
UVAPZ-2		4.50	4.46	4.42	4.43	
UVAPZ-3		3.04	3.46	3.41	3.38	
UVAPZ-4			7.23	5.79	5.85	
UVALP-1			3.55	3.49	3.70	
UVALP-2			4.25	3.66	3.71	
UVALP-3				3.51	3.56	
UVALP-4				3.31	3.53	
UVALP-5					3.60	
Lake level					3.45	

Date	7/9		7/12		7/18	
UVA well	Current (m)	High (m)	Current (m)	High (m)	Current (m)	High (m)
UVAMW-15					6.90	6.88
UVAMW-14					7.69	7.66
UVAMW-13					8.08	8.33
UVAMW-12					8.69	8.65
UVANW-11	9.38		9.38		9.57	9.41
UVANW-10	9.15	9.35	9.21	9.43	9.16	9.51
UVANW-9	9.25		9.29		9.47	9.49
UVANW-8	9.23	9.29	9.22	9.36	9.44	9.46
UVANW-7	9.33		9.34		9.46	9.42
UVANW-6	9.18	9.34	9.19	9.35	9.27	9.51
UVANW-5	9.78		9.77		9.83	
UVANW-4	8.60	8.64	8.62	8.63	8.63	8.84
UVANW-3	8.95		8.94		9.19	9.03
UVANW-2	8.28	8.43	8.30	8.57	8.30	8.62
UVANW-1	8.32		8.31		8.50	8.41
UVAPZ-1	3.78		3.75		3.77	
UVAPZ-2	4.37		4.34		4.31	
UVAPZ-3	3.35		3.31		3.26	
UVAPZ-4	5.79					
UVALP-1	3.74		3.74		3.82	
UVALP-2	3.67		3.67		3.63	3.73
UVALP-3	3.53		3.60		3.53	3.59
UVALP-4	3.49		3.51		3.60	
UVALP-5			3.58		3.57	3.68
Lake level	3.42		3.43		3.51	

	7/24		8/1		8/16	
UVA well	Current (m)	High (m)	Current (m)	High (m)	Current (m)	High (m)
UVAMW-15		6.89	6.94	6.87	6.92	6.90
UVAMW-14		7.67	7.67	7.55	7.63	7.67
UVAMW-13	8.09	8.02	7.98		7.95	8.13
UVAMW-12	8.54	8.68	8.69		8.43	8.54
UVAMW-11	9.58	9.54	9.49	9.54	9.48	9.50
UVAMW-10	8.97		9.13	9.32	9.28	9.48
UVAMW-9	9.42	9.30	9.25	9.38	9.31	9.42
UVAMW-8	9.43	9.48	9.26	9.44	9.36	9.51
UVAMW-7	9.52	9.37	9.33	9.46	9.39	9.44
UVAMW-6	9.20	9.51	9.17	9.38	9.35	9.58
UVAMW-5	9.75			11.79	9.67	
UVAMW-4	8.61		8.60	8.65	8.65	8.76
UVAMW-3	9.18	9.07		10.45	9.18	
UVAMW-2	8.32	8.65	8.30	8.60	8.47	8.59
UVAMW-1	8.45	8.43	8.42	8.44	8.41	8.44
UVAPZ-1	3.75		3.75		3.68	
UVAPZ-2	4.29		4.27		4.19	
UVAPZ-3	3.24		3.21		3.13	
UVAPZ-4						
UVALP-1	3.77				3.75	
UVALP-2	3.72	3.78		3.68	3.59	3.75
UVALP-3	3.48	3.56		3.50	3.50	3.61
UVALP-4	3.56				3.70	
UVALP-5	3.53	3.98		3.59	3.46	3.69
Lake level	3.46		3.41		3.48	

UVA well	8/24 Current (m)	High (m)	9/4 Current (m)	High (m)	9/14 Current (m)	High (m)
UVAMW-15	6.90	6.95			6.91	6.91
UVAMW-14	7.61	7.72			7.49	7.67
UVAMW-13	8.09	8.41	7.92	8.06		
UVAMW-12	8.46	8.47	8.32	8.43	8.38	8.43
UVAMW-11	9.49	9.50	9.40	9.50	9.41	9.41
UVAMW-10	9.35	9.47	9.15	9.31	9.10	9.31
UVAMW-9	9.34	9.38	9.26	9.31	9.28	9.32
UVAMW-8	9.28	9.48	9.21	9.30	9.26	9.32
UVAMW-7	9.46	9.43	9.39	9.39	9.39	9.39
UVAMW-6	9.35	9.45	9.22	9.38	9.37	9.34
UVAMW-5	9.66				9.60	
UVAMW-4	8.69				8.65	8.77
UVAMW-3	8.98	9.20	9.61			8.99
UVAMW-2	8.52	8.59	8.52			
UVAMW-1	8.39	8.44	8.37	8.39	8.34	8.37
UVAPZ-1	5.39		3.63		3.62	
UVAPZ-2	4.18		4.13		4.09	
UVAPZ-3	3.09		3.04		3.01	
UVAPZ-4						
UVALP-1	3.92		3.77			
UVALP-2	3.66	3.73	3.61	3.72	3.80	5.63
UVALP-3	3.37	3.63	3.42	3.59	3.48	4.68
UVALP-4	3.63		3.49		3.57	
UVALP-5	3.56	3.69	3.55	3.66	3.58	4.79
Lake lev.	3.46		3.39		3.44	

UVA well	9/25		10/18	
	Current (m)	High (m)	Current (m)	High (m)
UVAMW-15	6.84	6.97		
UVAMW-14	7.46	7.54		
UVAMW-13			7.80	8.01
UVAMW-12	8.41	8.41	8.38	8.42
UVAMW-11	9.33	9.41	9.28	9.38
UVAMW-10	9.16	9.17	9.06	9.18
UVAMW-9	9.27	9.28	9.27	9.28
UVAMW-8	9.25	9.29	9.22	9.28
UVAMW-7	9.37	9.37	9.30	9.32
UVAMW-6	9.29	9.37	9.21	9.33
UVAMW-5				
UVAMW-4	8.55	8.62		
UVAMW-3		8.94		
UVAMW-2	8.49	8.55	8.39	8.54
UVAMW-1	8.39	8.36	8.34	8.36
UVAPZ-1				
UVAPZ-2				
UVAPZ-3				
UVAPZ-4				
UVALP-1				
UVALP-2				
UVALP-3		3.26		
UVALP-4				
UVALP-5		3.61		

Appendix 3. Water Level Measurements - ESI Wells

Appendix 3. Summary of water level measurements from ESI wells. All values expressed in absolute elevation above mean sea level.

ESI Well	6/6 (m)	6/13 (m)	6/21 (m)	6/27 (m)	7/2 (m)	7/9 (m)	7/12 (m)
ESI MW-4	9.45	9.35	9.31	9.27	9.25	9.18	9.21
ESI MW-2	9.27	9.22	9.17	9.14	9.11	9.07	9.06
ESI MW-7	7.93	7.88	7.83	7.79	7.79	7.72	7.69
ESI MW-5	5.61	5.57	5.55	5.51	5.49	5.46	5.42
ESI MW-12		5.71	5.68	5.64	5.62	5.58	5.56
ESI MW-11		6.28	6.25	6.21	6.16	6.13	6.06
ESI MW-10		6.79	6.73	6.69	6.63	6.56	6.53
ESI MW-13	4.80	4.77	4.73	4.70	4.68	4.66	4.64
ESI MW-9	5.13	5.09	5.06	5.02	5.01	4.96	4.96
ESI MW-6	6.38	6.33	6.27	6.22	6.18	6.13	6.10
ESI PZ-2	4.52	4.48	4.45	4.45	4.40	4.37	4.35
ESI PZ-3	3.24	3.22	3.19	3.19	3.20	3.18	3.18
ESI MW-3							

	7/18 (m)	7/24 (m)	8/1 (m)	8/16 (m)	8/24 (m)	9/4 (m)
ESI MW-4	9.28	9.18	9.16	9.13	9.12	
ESI MW-2	9.02	8.98	8.93	8.84	8.81	
ESI MW-7	7.68		7.60	7.56	7.49	
ESI MW-5	5.43	5.40	5.38	5.34	5.32	
ESI MW-12	5.54	5.52		5.43	5.42	5.38
ESI MW-11	6.08	6.03		5.94	5.92	5.86
ESI MW-10	6.48	6.44		6.28	6.26	6.20
ESI MW-13	4.66	4.63	4.60	4.60	4.58	4.55
ESI MW-9	5.05		4.92		4.99	4.86
ESI MW-6	6.10	6.05	6.00		5.89	5.82
ESI PZ-2	4.38	4.35	4.31	4.30	4.30	4.24
ESI PZ-3	3.22	3.20	3.14		3.24	3.44
ESI MW-3	14.29	14.26	14.25	14.21	14.20	