REPORT OF THE JOINT TASK FORCE

INSTREAM FLOW NEEDS ANALYSIS

FOR

NORTHERN NEW CASTLE COUNTY, DELAWARE

PHASE ONE: 7Q10 ASSESSMENT

Delaware Department of Natural Resources & Environmental Control, Water Resources and Fish & Wildlife Divisions

Delaware Geological Survey

Pennsylvania Department of Environmental Resources

Water Resources Agency for New Castle County

City of Wilmington

City of Newark

Artesian Water Company

United Water Delaware

<u>Technical Advisors</u>

Delaware River Basin Commission

Delaware Nature Society

June 15, 1995

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ACKNOWLEDGEMENTS

The participation of the multi-disciplinary Instream Flow Needs Joint Task Force in the development of this study and report is gratefully acknowledged. Special thanks is extended to United Water Delaware (formerly Wilmington Suburban Water Corporation) for making available additional stream cross-section work at the Stanton intake for use in the HEC-2 model runs of that study reach. Particular thanks also goes to the Water Resources Agency for New Castle County for invaluable assistance in the modeling. The diligence and dedication of the Study Coordinating Group was vital to the success of this study effort and is sincerely acknowledged. Membership included Stewart Lovell, P.G. and Richard W. Greene, Environmental Engineer, from the Water Resources Division, Department of Natural Resources and Environmental Control; Gerald J. Kauffman, P.E., Water Resources Engineer, Water Resources Agency for New Castle County and David C. Yaeck, consultant and Joint Task Force Chairman.

EXECUTIVE SUMMARY

The draft Scope of Work for the Instream Flow Needs Analysis for Northern New Castle County, Phase One: 7Q10 Assessment was distributed to the multi-disciplinary Joint Task Force in advance of the initial meeting held September 12, 1994 in Clayton Hall at the University of Delaware for review and comment. Detailed discussion of the target fish species selected for protection during the 7Q10 analysis led to minor revisions in the Scope guided by input from the Division of Fish & Wildlife, Delaware Department of Natural Resources and Environmental Control. Some revisions were also made to the selected study reaches on the White Clay Creek and the Brandywine with the major water supply intakes as the focus. The Scope of Study was then unanimously approved by the Joint Task Force. Stewart Lovell, P.G. and Richard W. Greene, environmental engineer, of the Water Resources Division, DNREC; Gerald J. Kauffman, P.E. water resources engineer for the Water Resources Agency for New Castle County; and David C. Yaeck, consultant and Joint Task Force chairman, were announced as the coordinating group for implementation of the study.

The initial tasks to be undertaken were data compilation, geographic information system plots of water supply intakes and study reaches and a comparison of 7Q10 flows. A public briefing was held at the same location following the Joint Task Force session to explain the study goals and methodology.

Prior to the October 28 meeting of the Joint Task Force, discussions were held with Greene, Lovell and Kauffman regarding the use of a hydraulic model to project stream depth and velocity for a given flow rate. The suggestion was advanced to purchase the HEC2 model and recommended stream cross-sections developed by the Federal Emergency Management Agency (FEMA) in the study reaches would also be obtained. The flexibility of this approach enables evaluation of various flows, including the minimum depths and velocities.

Initial model runs were presented at the Joint Task Force meeting in January 1995. GIS mapping of the study reaches continued to be refined by the Water Resources Agency for New Castle County. Upon receipt of the FEMA cross-section data, it was determined that some additional information would be required. The Task Force agreed to a recommendation that ten additional cross-sections should be conducted on the Brandywine, Christina and White Clay. Verification of the FEMA data would be accomplished at the same time by selecting one cross-section in each study reach. This work was carried out by an outside contractor in April 1995. The field survey cross-sections and stream flow data were incorporated into the HEC2 model to predict depth and velocity for the given 7Q10 at each study reach. The 7Q10 is defined as the low flow likely to occur for 7 consecutive days, once every 10 years. Stream flow exceedance records indicate the 7Q10 is normally exceeded 98% of the time. Preliminary results from HEC2 computer model runs for the four study areas conducted by Kauffman indicate the 7Q10 flow on the Brandywine at Wilmington exceeds a depth of one foot along 87% of the study reach. For the Christina River at Smalley's Pond, the 7Q10 flow exceeds a depth of one foot along 98% of the study reach. On the White Clay Creek at Stanton, the 7Q10 flow exceeds a depth of one foot along 90% of the reach and 75% of the study reach on the White Clay at Newark.

Based on data from Bovee (1975) cited in Designing and Negotiating Studies Using IFIM published by the U.S. Fish and Wildlife Service, this depth of one foot and the velocities recorded in the model runs meet the minimum criteria as recommended of most of the target species identified for this study in those portions of the study reaches previously stated. Criteria for the habitat of the white perch has yet to be established because a thorough literature review on this subject was beyond the scope of the Phase One Study. Habitat substrate requirements have not been included in the 7Q10 assessment and should be the subject of additional study.

The HEC2 model runs disclose the 7Q10 depths are less than one foot along the riffle sections just downstream from the dam between Market Street and Baynard Boulevard and downstream from City Dam on the Brandywine at Wilmington. A similar situation occurs in the riffle sections just downstream from the small dams within the study reach on the White Clay at Newark. Additional HEC2 model runs were conducted by Kauffman and Greene following receipt of the cross-section work performed by Tetra Tech under contract with the Department of Natural Resources and Environmental Control. The results are incorporated in the graphics contained in this report.

Utilization of the HEC2 model to conduct wetted perimeter analysis of the study reaches was considered initially for inclusion in the Phase One Study, but sufficient habitat evaluation was deemed lacking to provide a beneficial series of model runs. Similarly, the Fish and Wildlife Division of the Delaware Department of Natural Resources and Environmental Control expressed reservation concerning the development of a statewide policy regarding instream flow needs based on the general approach to target fish species used in the Phase One assessment. Meeting on April 13, 1995, the Joint Task Force acknowledged the need for additional information relating flow rates and depths to the fish habitat within the study reaches and to the need for re-examination of the target species to determine if there are other species that might serve as more sensitive indicators of instream flow needs. Additional funding for a Phase Two of the 7Q10 assessment project to address these issues was recommended by the Joint Task Force.

1. INTRODUCTION

The issues of instream flow needs and passby requirements for public water supply intakes on the streams of Northern New Castle County, Delaware were brought into focus by action of the Delaware River Basin Commission which imposed a 7Q10 passby on the Wilmington Suburban Water Corporation's intake (now United Water Delaware) at Stanton in 1993. The Commission had taken similar action on the City of Newark's White Clay intake in 1991. Under terms of the DRBC allocation permits, the City of Newark and Wilmington Suburban Water Corporation must curtail withdrawals when minimum passby flows along the White Clay Creek reach 14 mgd and 17.2 mgd, respectively. The water allocation permits issued by the Delaware Department of Natural Resources and Environmental Control contained no such passby requirements and no state regulation exists which would mandate the imposition of such a flow regime on the public water purveyors.

However, in April 1993, DNREC's Water Resources Division conducted a workshop regarding a proposed Statewide Policy for Minimum Passby Streamflow Requirements for Major Surface Water Withdrawal Projects. The policy also proposed the exemption of agricultural irrigation. The rationale advanced by the Department for the formulation of the proposed policy emphasized the steady increase over time of withdrawals from the surface waters for public water supply and other uses and a reasonable potential for such withdrawals to create competition and conflict with other beneficial uses such as the propagation of fish, aquatic life and wildlife, especially during the time of critical low flow.

As a result of the workshop, it was determined a study of instream flow needs was appropriate prior to the consideration and adoption of a statewide policy for passby requirements. An initial draft for such an analysis was prepared by the Water Resources Agency for New Castle County in May, 1994 for review and comment by the Christina River Basin Drought Management Committee with membership from the various governmental agencies and water purveyors in Delaware and Pennsylvania.

The Water Resources Division of DNREC agreed the instream flow needs analysis was a logical step in the formulation of statewide policy and funding was available to proceed on a limited basis. David C. Yaeck Consulting Services of West Chester, Pennsylvania was retained to move the process forward. Revision of the original Water Resources Agency for New Castle County proposal resulted in a work plan to assess the impact of a 7Q10 passby flow requirement at the four major public water supply intakes located on the streams in northern New Castle County, Delaware.

1.1 BACKGROUND

The establishment of technically-based minimum instream (passby) flow requirements is an emerging need for water supply management in northern New Castle County, Delaware. Other states in the Eastern USA have or are currently establishing minimum instream flow standards for surface water supply as well as aquatic habitat, fishery, and recreation management purposes. At a workshop in April, 1993, the Delaware Department of Natural Resources and Environmental Control (DNREC) circulated a draft water supply policy which, in the absence of available alternate information, offered the 7Q10 design flow as the minimum passby flow requirement for surface water withdrawal projects. The Water Supply Plan for New Castle County (Churchman's EIS) computed safe yield and existing/future water supply needs using the 7Q10 flow as a minimum flow standard.

For the first time, the Delaware River Basin Commission (DRBC) implemented a minimum 7Q10 instream flow requirement in New Castle County in 1991 at the new City of Newark Water Treatment Plant along the White Clay Creek. In August 1993, the Delaware River Basin Commission (DRBC) imposed a 7Q10 passby flow standard for the Wilmington Suburban Water Corporation's surface water withdrawal along the Red Clay and White Clay Creeks at Stanton, Delaware. Unless an Operation Plan is implemented, imposition of the 7Q10 standard at the Wilmington Suburban Stanton Plant for water supply and aquatic habitat protection purposes has the potential to curtail surface water withdrawals during the warm, dry periods of the year. A formal instream flow analysis is needed to verify the 7Q10 or some other standard as appropriate for the unique water supply and aquatic habitat circumstances in northern New Castle County.

Surface Water Withdrawals

There are four major public surface water withdrawals and 21 others along Christina River Basin streams in New Castle County. The City of Wilmington withdraws water from the Brandywine Creek through a raceway for treatment, storage in Hoopes reservoir or other impoundments, and distribution to customers. The privately-owned Wilmington Suburban Water Corporation withdraws water from the tidal Red Clay and White Clay Creeks at the Stanton Filter Plant. Wilmington Suburban also withdraws surface water from the Upper Christina River at Smalley's Pond impoundment. The City of Newark operates a recently installed surface water intake, treatment plant, and USGS gaging station along the White Clay Creek several miles upstream from the Wilmington Suburban Stanton Plant.

The establishment of a technically-based instream flow standard at each of the withdrawal points is desirable to provide for sufficient flow for water supply purposes and, at the same time, affording protection to habitat, recreation and other instream uses. An evaluation of the 7Q10 is needed to determine whether this standard provides adequate flow to meet these multiple needs.

Christina River Basin

The citizens and businesses of northern New Castle County obtain over 70 percent of their potable water from the four major watersheds in the Christina River Basin. The 565-square mile basin originates in the headwaters of Pennsylvania and Maryland. The Piedmont streams then flow south into New Castle County, Delaware before joining the Delaware River at Wilmington. The four major streams with major surface water withdrawals in New Castle County include the Brandywine Creek, Red Clay Creek, White Clay Creek, and the Christina River. The DRBC regulates water supply withdrawals in the bi-state Christina Basin in Pennsylvania and Delaware. The Delaware DNREC is responsible for water allocation permitting and water supply regulation in Delaware. The Water Resources Agency for New Castle County is responsible for regional water supply planning and management in the northern Delaware portion of the basin. Overall, instream flow and drought warning coordination between agencies and utilities in Pennsylvania and Delaware is provided by the watershed-based Christina River Basin Drought Management Committee.

Status of Instream Flow Analysis

As previously noted, the Delaware River Basin Commission has imposed a 7Q10 minimum flow standard or passby requirement for two of the four public water supply withdrawals in New Castle County (City of Newark and Wilmington Suburban). The Commonwealth of Pennsylvania adheres to a similar standard in the headwaters of the Christina River Basin. No passby requirement has yet been imposed on the other withdrawals from the waters of the Basin in New Castle County. Management of surface water withdrawals with establishment of minimum flow limits at the Wilmington Suburban Water Corporation Stanton Plant is complex due to the hybrid freshwater stream flow and tidal nature of the Red Clay and White Clay Creeks at the withdrawal. The City of Newark along the White Clay Creek must curtail water withdrawals when stream flows at the downstream Stanton plant reaches 7Q10 depth or flow. The City of Wilmington withdrawal along the Brandywine Creek does not currently have an instream flow standard. However, one may be imposed in the future. Development of a minimum passby flow standard at Wilmington along the Brandywine Creek should reflect the withdrawal via a raceway and diversion of excess water back into the Brandywine approximately a mile downstream from the intake. The Wilmington Suburban intake along the Upper Christina River at the Smalley's Pond impoundment currently has no formal minimum flow standard.

Aquatic Environment

Commonly, instream flow studies address the minimum flow for water supply and aquatic environment protection purposes. The State of Delaware Surface Water Quality Standards provide minimum criteria to protect the stream environment in New Castle County. The Standards specify chronic aquatic toxicity criterion based on the 7Q10 flow in streams. The standards also include the designated uses of the Christina Basin streams which include public water supply, industrial water supply, primary/secondary contact recreation, fish/aquatic life, cold water fish, and agricultural water supply. Common fish species in the Christina Basin which would require minimum flow depths for habitat protection include:

Brandywine Creek	Smallmouth Bass and Rock Bass
Red Clay and White Clay Creeks (tidal)	Catfish species and White Perch
White Clay Creek (freshwater)	Brown Trout, Rainbow Trout
Upper Christina River	
- Above Smalley's Pond	Rainbow Trout & Redbreast Sunfish
- Below Smalley's Pond	Catfish species and White Perch

1.2 STUDY OBJECTIVES

The objective of this study was to assess the effectiveness of a 7Q10 minimum flow standard in the protection of all instream uses, including water supply, aquatic habitat recreation. The study was conducted by a multi-disciplinary Joint Task Force drawn from the membership of the interstate Christina River Basin Drought Management Committee and such other additional members which are deemed necessary to the task. Consultant David C. Yaeck was responsible for the overall direction of the study and coordination of the Joint Task Force activities as Chairman.

The Delaware Department of Natural Resources and Environmental Control, Water Resources Division, was responsible for the retrieval of requested data bases required for Joint Task Force assessment, including fisheries, biological, chemical, substrate sampling programs and the location of the sampling points via longitude/latitude for development of a historical record. DNREC, Water Resources Division, was further responsible for the conduct of any additional sampling required by the Joint Task Force to carry out its mission.

The Geographic Information Systems (GIS) capability of the Water Resources Agency for New Castle County was utilized to the fullest extent possible during the 7Q10 assessment program. All major water withdrawals and discharges were mapped as well as all sampling points for the various DNREC water quality investigations. An appropriate mapping scale existed within the Agency and was utilized to present the data in graphic form via latitude/longitude for the historical record. The Agency was also requested to prepare a GIS mapping of the designated uses for the various stream segments in the Christina Basin in the county.

The services of the Delaware Geological Survey (DGS) were employed to develop the 7Q10 flow at each intake identified in the Christina River Basin in Northern New Castle County to aid the Joint Task Force in determining the adequacy of such a standard at each location in meeting the overall goal of instream use protection. Additionally, DGS was requested to determine the base flow at each recording stream gage in Christina Basin waters to provide a comparison with 7Q10 flow at that gage or, by interpolation, at other such points as may be requested by the Joint Task Force.

In performing the 7Q10 assessment, the Joint Task Force took into consideration all designated uses assigned to the Christina Basin streams by DNREC and the instream flow needs of each category. Following the evaluation of all available data and such other information additionally requested, the Joint Task Force concluded its activities with the issuance of a report to the Department of Natural Resources and Environmental Control. The report stated insufficient habitat data existed to enable development of a position regarding the 7Q10 minimum flow standard as it applies to the protection of all instream uses in Northern New Castle County or such other minimum flow which may be appropriate.

The 7Q10 assessment took into consideration the use of such a standard for the following water resources management activities:

- DRBC and DNREC Surface Water Allocation and Withdrawal Permits
- Christina Basin Drought Management Committee Low Flow Forecasts

- Churchman's EIS Water Supply Alternative Analysis
- Efficient water supply operations and management by the private and public utilities to prevent curtailment of withdrawals during low flow periods
- Protection of streams for water supply, fisheries, aquatic habitat and recreational designated uses

1.3 SCOPE OF WORK

1. Joint Task Force: a multi-disciplinary study group was formed consisting of a project coordinator acting as chairman, hydrologists, biologists, environmental scientists and water resource planners to guide and direct the 7Q10 assessment. The Task Force met regularly at critical milestones to review and guide management of the work. Task Force membership was drawn from the existing Christina River Basin Drought Management Committee and included the following members:

   - David C. Yaeck, Project Coordinator
   - Delaware River Basin Commission
   - Delaware Department of Natural Resources and Environmental Control
     - Division of Water Resources
     - Division of Fish and Wildlife
   - Delaware Geological Survey
   - Pennsylvania Department of Environmental Resources
   - Water Resources Agency for New Castle County
   - New Castle County Private/Public Water Utilities

2. Interdisciplinary Tasks: Within the Task Force, certain staff were designated to carry out specific functions necessary to the study including disciplines associated with water supply, water quality and other instream uses. Other instream interests served as resource persons by the Task Force.

3. Data Review and Collection: An Ad Hoc Committee was created within DNREC to assist the Task Force by providing for appropriate data retrieval and additional data collection necessary to the 7Q10 assessment. A preliminary literature search was conducted to review instream flow standards established by others in waterways affected by tide.

4. Stream Flow Analysis: The Delaware Geological Survey was requested to establish the 7Q10 flow at all points of public water supply withdrawal in the Christina Basin in Northern New Castle County. This analysis allowed review of the impact of 7Q10 low flow utilization on all withdrawals within the study area.

5. Study Reaches: In addition to the 7Q10 assessment conducted at the various points of withdrawal, the Task Force determined it desirable to conduct a stream reach analysis. The following list has been developed by the Water Resources Agency for New Castle County and amended by the Joint Task Force involving the public water supply intakes and a listing will have to be developed for the other withdrawal points should this course of study be pursued.

- Brandywine Creek - One and a half mile-long reach adjacent to the Wilmington Water Supply raceway withdrawal at Brandywine Park. The study limits extend from the C & O railroad bridge downstream to the Market Street Bridge.

- White Clay Creek - Two mile-long reach adjacent to the Wilmington Suburban Water Company withdrawal at Stanton. The study limits extend from the Route 4 bridge downstream to Churchmans Marsh.

- White Clay Creek - One and a half mile-long reach adjacent to the City of Newark water treatment plant near Paper Mill Road.

- Christina River - Two mile-long reach adjacent to the Wilmington Suburban Water Company intake at Smalley's Pond. Study limits extend from one-half mile upstream from Smalley's Pond downstream to the Route 273 bridge.

6. Designated Stream Uses: Information regarding the designated stream uses established by DNREC was furnished to the Task Force to assist in the evaluation of 7Q10 low flow standard. The information was plotted via GIS and included the following:

- Public, industrial, agricultural water supply
- Primary contact recreation
- Secondary contact recreation
- Fish, aquatic life, wildlife
- Put and take cold water fish

7. Aquatic Biology: The Task Force reviewed pertinent data relating to the

key aquatic species requiring minimum flows at each study location and concluded additional study would be required under Phase Two.

8. Public Water Supply Issues: Unique hydrologic circumstances exist which effected 7Q10 assessments involving the public water supply intakes located in Christina Basin waters. The Water Resources Agency for New Castle County has detailed this information for the benefit of the Joint Task Force:

- City of Wilmington Surface Water Intake - The minimum instream flow criteria at this surface water withdrawal should reflect the presence of a unique diversion raceway and supplemental releases from Hoopes Reservoir. Raw water is withdrawn from the Brandywine Creek via a mile-long raceway. Excess water is diverted back into the Creek. During certain dry flow periods, the section of Creek between the upstream and downstream ends of the raceway reaches low pool depths. Creek flow is impounded in the reach adjacent to the raceway by several dams. The City has significant storage available at Hoopes Reservoir for supplemental releases back to the City system.

- Wilmington Suburban Stanton Plant at White Clay Creek and Red Clay Creek - Instream flow standards should reflect possible supplemental releases from Hoopes Reservoir into Red Clay Creek, the tidal flow in the creeks at the intake, and the need to provide sufficient freshwater for salt front maintenance. The available methods (7Q10, Wetted Perimeter, IFIM) are primarily freshwater stream flow conditions and must be applied judiciously for the unique tidal situation at Stanton.

- City of Newark Water Withdrawal at White Clay Creek - Instream flow standards should reflect the "first in right" allocation status of the downstream Wilmington Suburban plant at Stanton. When the White Clay Creek at Stanton reaches the minimum passby flow permitted by DRBC, the City of Newark may have to curtail water withdrawals to maintain sufficient passby flow for aquatic habitat protection and downstream water supply purposes.

- Wilmington Suburban, Christina River Plant at Smalley's Pond - Raw water is directly withdrawn from an on-stream impoundment as opposed to a free flowing stream. The instream flow standard at this location should reflect that the Smalley's Pond dam will impound water at the intake during low flow periods.

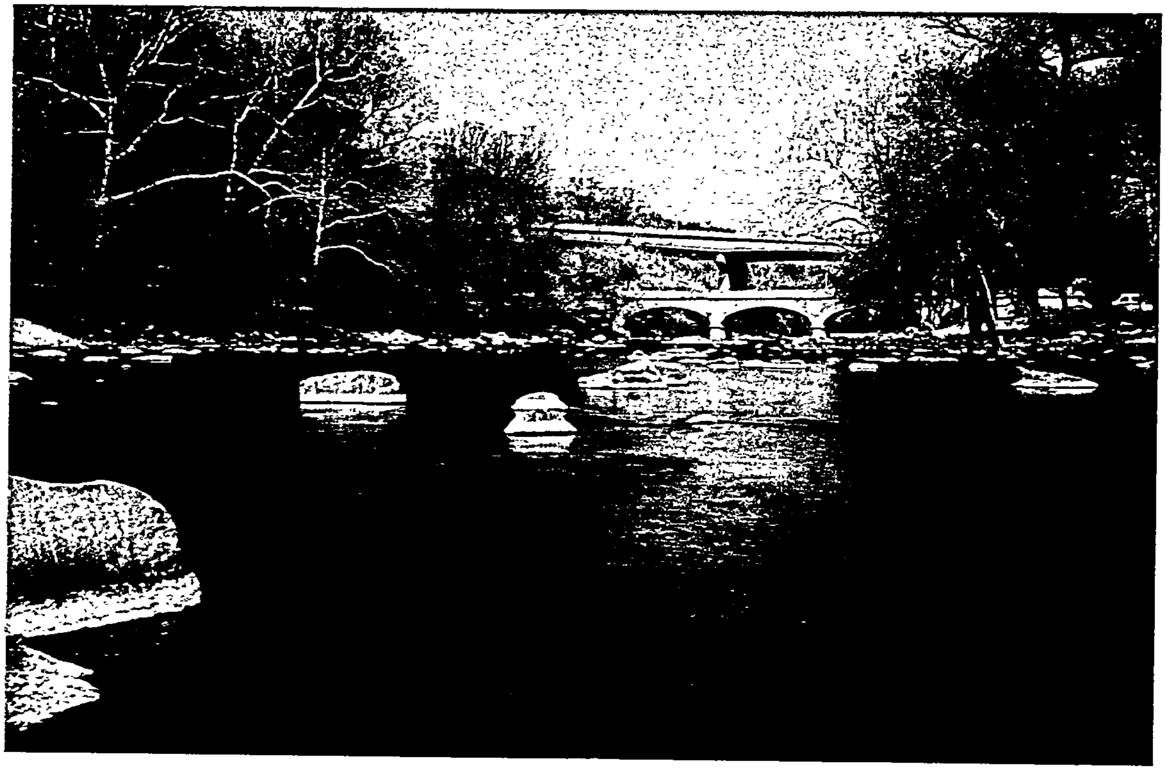
9. <u>7Q10 Method</u>: For the purposes of this assessment, a modified 7Q10 Method was cited as a guide for the Joint Task Force. Further revision was suggested during initial Task Force discussions and consultation with the Delaware Geological Survey:

- Determine the 7Q10 discharge at each of the withdrawal and discharge points reported by DNREC.
- Determine the 7Q10 depth, stage and velocity at the stream cross-sections.
- Plot the 7Q10 depth and stage on the stream cross-sections
- Using the stream cross-sections, determine if the 7Q10 depth and velocity are suitable for the designated uses of the stream. The Joint Task Force evaluated the sufficiency of the 7Q10 to protect the fish species of concern.

10. <u>GIS Mapping</u>: The Water Resources Agency for New Castle County provided GIS mapping capability for the study effort. Products included withdrawals and discharges in the study area, water quality sampling locations and designated stream uses on the various reaches. The maps are included in the final 7Q10 assessment report.

11. <u>Public Participation</u>: Several public information briefings and comment meetings were scheduled to receive additional input to the project effort.

12. <u>Final Report</u>: The final report of the 7Q10 assessment was prepared by the Study Coordinating Group for review, comment, and adoption by the Joint Task Force. Comments were also solicited from other interested parties. The final report was submitted to the Delaware Department of Natural Resources and Environmental Control for consideration of the Joint Task Force recommendations.



PHOTOGRAPH 1

Brandywine Creek at Wilmington

PHOTOGRAPH 2

Christina River at Smalley's Pond

2. METHODS

2.1 OVERVIEW OF AVAILABLE INSTREAM FLOW METHODOLOGIES

The Instream Flow Needs Joint Task Force (JTF) considered the following methodologies for the analysis:

- 7Q10 Assessment
- Wetted Perimeter
- Instream Flow Incremental Methodology (IFIM)

A literature search of the available methodologies indicated that each was appropriate for the unique hydrologic and aquatic habitat conditions along the Piedmont streams of northern New Castle County. The 7Q10 Assessment and Wetted Perimeter are considered to be "mid-level" techniques to define minimum instream flow standards. The IFIM approach was developed by the U. S. Fish and Wildlife Service as one of the more sophisticated techniques.

Given limited time and budget, the Joint Task Force decided to conduct the 7Q10 Assessment as Phase I of a possible multi-phase approach. The Wetted Perimeter and IFIM approaches were reserved as possible methodologies in future phases, should the Joint Task Force determine additional study is needed to evaluate the adequacy of the 7Q10 to protect habitat and provide sufficient water supply.

The Phase I 7Q10 Assessment was conducted according to the following study approach:

1. Identify a study reach at each of the four major public water supply intakes.

2. Determine 7Q10 at each intake.

3. Obtain HEC-2 hydraulic model data files from the Federal Emergency Management Agency (FEMA).

4. Supplement the HEC-2 model with field survey cross-sections, as necessary.

5. Use the HEC-2 hydraulic computer model to calculate depth, velocity, and wetted perimeter associated with the 7Q10 during low tide conditions.

6. Plot the 7Q10 depth and velocity on stream cross-sections and stream profiles within the four study reaches.

7. Conduct a preliminary literature search to obtain minimum fish habitat criteria cited by Bovee, and the South Carolina Marine and Fish Wildlife Department.

8. Compare the computed 7Q10 depth and velocity to minimum criteria needed by selected fish species at each study area.

9. Present findings to Joint Task Force.

10. Joint Task Force reviews findings and determines if 7Q10 depth and velocity are sufficient to meet fishery criteria as defined by the U. S. Fish and Wildlife Service and the Delaware DNREC, Division of Fish and Wildlife.

2.2 SELECTION AND DESCRIPTION OF STUDY REACHES

The selected study reaches consist of the four major public water supply withdrawals in the Christina Basin of Northern New Castle County (Figure 1). The four (4) study reaches include:

1. Brandywine Creek at Wilmington adjacent to the two City of Wilmington surface water supply intakes (Figure 2).

2. Christina River at Smalley's Pond adjacent to the United Water Delaware (formerly Wilmington Suburban Water Corporation) water supply intake at the Christiana Water Treatment Plant (Figure 3).

3. White Clay Creek at Newark adjacent to the City of Newark's Paper Mill Road Surface Water Treatment Plant (Figure 4).

4. White Clay Creek and Red Clay Creek at Stanton adjacent to the United Water Delaware's Stanton Filter (Figure 5).

Figures 6 through 9 summarize flow diagrams for each of the 4 study areas during a typical low-flow period in October, 1994.

Table 1 summarizes the 25 water supply withdrawals in the Christina Basin in Delaware. The Joint Task Force considered the possibility of conducting a 7Q10 Assessment at each of the 25 industrial, irrigation, recreational, and public water supply withdrawals in the Christina basin. The four major public water supply intakes account for the majority (87%) of the withdrawals in the Christina Basin of Delaware. Therefore, the Joint Task Force decided to focus efforts on evaluating the adequacy of the 7Q10 as a minimum instream flow standard at the four major public water supply intakes. These four intakes account for 85 million gallons per day (mgd) of the total 98 mgd available pumping capacity.

2.3 SPECIFICATION OF 7Q10 AND WITHDRAWAL CAPACITIES

Table 2 summarizes the 7Q10 and maximum withdrawal capacity for the stream and intake, respectively, at each of the four study areas. The 7Q10 at each intake was derived by Metcalf and Eddy, Inc. (1991) using USGS stream gage data for the period of record. The maximum withdrawal capacity was provided by the water suppliers with verification by Delaware DNREC and Delaware River Basin Commission (DRBC) water supply allocation dockets.

The DRBC has directed, in lieu of alternative criteria, that the 7Q10 is the minimum flow standard at the two White Clay Creek intakes. The Brandywine Creek and Christina River have no formal minimum 7Q10 flow requirement.

The 7Q10 is defined as the low flow likely to occur for 7 consecutive days, once every 10 years. Stream flow exceedance records indicate the 7Q10 is normally exceeded 98% of the time (358 to 359 days of the year).

The total surface water supply withdrawal capacity at the four intakes is 85 mgd, which can provide over 70% of the potable water supply for New Castle County. The City of Wilmington and United Water Delaware Stanton withdrawals account for approximately 55% and 35%, respectively, of the developed 85 mgd capacity.

2.4 GIS MAPPING

The Water Resources Agency for New Castle County summarized the study reaches and associated data on a 5-map series for the Phase I - 7Q10 assessment (Figures 1 through 5). The digital mapping was prepared on the Agency's AERI II data management system in an ARC-INFO format. The digital mapping summarizes the following coverages pertinent to the analysis (with sources listed):

- Roads, Highways, and Railroads (DelDOT)
- Hydrology and Streams (DelDOT)

- Watersheds (USDA-SCS)
- Public Water Supply Intakes (DNREC)
- Stream Monitoring Stations (DNREC)
- Stream Gages (USGS)
- Water Supply Wells (DNREC)
- NPDES Discharges (DNREC)
- Precipitation Gages (USNWS).

2.5 SELECTION OF TARGET SPECIES

The Joint Task Force considered native and non-native fish species requiring minimum instream flow protection at each of the four study areas. The selected species are considered to be significant recreational sport fisheries worthy of minimum flow protection. After a review and discussion, the Joint Task Force selected the following fisheries of concern as the initial focus of the Phase I - 7Q10 Assessment:

- Brandywine Creek (Smallmouth Bass and Rock Bass)
- Red Clay Creek and White Clay Creek (tidal) (Catfish species and White Perch)
- White Clay Creek (freshwater) (Brown Trout and Rainbow Trout)
- Upper Christina River
  - Above Smalley's Pond (Rainbow Trout and Redbreast Sunfish)
  - Below Smalley's Pond (Catfish species and White Perch)

2.6 SELECTION OF HABITAT SUITABILITY GOALS

The Joint Task Force conducted a preliminary literature search to quantify minimum 7Q10 depth, velocity, and habitat criteria for the selected fish species. Tables 3A, 3B, and 3C provide depth, velocity, and substrate habitat criteria for the selected fish species. This information was derived by Bovee in 1975 as published in Designing and Negotiating Studies using IFIM, by the U.S. Fish and Wildlife Service. The South Carolina Wildlife and Marine Resources Department suggested a minimum depth of one foot for Redbreast Sunfish. With the exception of Rock Bass, which is listed to have a minimum depth of 2 feet, all of the selected species require a minimum one feet flow depth. This fish habitat criteria developed by Bovee provided initial data to evaluate the adequacy of the 7Q10 for habitat protection. The fish criteria developed by Bovee were found to be insufficient pending a more detailed literature search and field evaluation. A more intensive literature search and fish habitat assessment will be conducted during Phase II to refine criteria for the ultimately-selected fish species.

2.7 HYDRAULIC MODELING

The Joint Task Force selected the U.S. Army Corps of Engineers HEC-2 hydraulic computer model to compute depth, velocity, and wetted perimeter for the selected 7Q10 at each of the four study areas. HEC-2 input data files were obtained from the Federal Emergency Management Agency (FEMA) for the Brandywine Creek, White Clay Creek, Red Clay Creek, and Christina River in New Castle County, Delaware. The HEC-2 input files provided existing stream cross-section and Manning's roughness ("n") values originally prepared for floodplain delineation purposes (Table 4).

The HEC-2 files were input to mini-computer (personal computer) and modified to include the 7Q10 flow at each study area. The predicted 7Q10 depth, velocity, and wetted perimeter were computed by HEC-2 using Manning's Open Channel Flow Equation modified by a Step Backwater Technique. All 7Q10 calculations for the Brandywine Creek, White Clay Creek, and Christina River were computed at the critical low flow condition which is low tide. Excerpts of the calibrated HEC-2 input and output files are summarized in Appendices A, B C, and D.

The original HEC-2 files from FEMA were modified as follows:

Brandywine Creek at Wilmington

- Insert starting water surface elevation = (-)1.53 feet (National Geodetic Vertical Datum of 1929) for low tide.
- Insert 7Q10 = 49.31 mgd = 76.3 cfs.
- Insert four field survey cross-sections at stream miles 2.55, 2.67, 2.93, and 2.99. These cross-sections were field surveyed by Tetra-Tech in April, 1995.
- Compute 7Q10 depth, velocity, and wetted perimeter for 17 stream cross-sections along the one and a half-mile reach.

Christina River at Smalley's Pond

- Insert starting water surface elevation = (-)1.53 feet (NGVD of 1929) for low tide.
- Insert 7Q10 = 2.1 mgd = 3.2 cfs.
- Insert two cross-sections at station 59+207 and 59+926 feet above the

stream mouth as field surveyed by Tetra-Tech on April, 1995.

- Compute 7Q10 depth, velocity, and wetted perimeter for 14 sections along the two-mile study reach.

White Clay Creek at Newark

- Insert starting water surface elevation = 46.7 feet (NGVD) at top of dam downstream from Paper Mill Road.
- Insert 7Q10 = 7.3 mgd = 11.3 cfs.
- Insert four cross-sections at stations 55+713, 56+623, 57+030, and 57+970 above the stream mouth as field surveyed by Tetra-Tech in April, 1995.
- Compute 7Q10 depth, flow, and wetted perimeter for 25 stream cross-sections along the two-mile stream reach.

White Clay Creek at Stanton

- Insert 7Q10 = 17.2 mgd = 26.6 cfs.
- Insert starting water surface elevation = (-)1.53 feet (NGVD) at low tide.
- Insert additional stream cross-sections provided by United Water Delaware as surveyed by Duffield Associates, Inc. in 1994 and 1995.
- Compute 7Q10 depth, velocity, and wetted perimeter for 27 sections along the two-mile stream reach.

2.8 COLLECTION OF SUPPLEMENTAL CROSS-SECTIONS AND VELOCITY MEASUREMENTS

The Delaware DNREC commissioned Tetra-Tech to obtain additional stream cross-sections to calibrate the HEC-2 model. The field survey data is summarized in Appendix E. In April, 1995, Tetra-Tech field survey crews obtained the following ten cross-sections with a flow and velocity measurement at each of the following ten study reaches:

- Brandywine Creek - Sections 2.55, 2.67, 2.93, 2.99. Velocity (0.53 fps) and flow measurements (138.78 cfs = 89.6 mgd) were obtained at Section 2.55.
- Christina River - Sections 59+207 and 59+926. Velocity (0.20 fps) and flow (14.6 cfs = 9.4 mgd) measurements were obtained at Section 59+926.
- White Clay Creek at Newark - Sections 55+713, 56+623, 57+030, and 57+970. Velocity (0.89 fps) and flow measurements (38.8 cfs = 25.0

mgd) at were obtained at Section 57+030.

- White Clay Creek at Stanton - No additional sections needed.

The additional stream cross-sections were inserted to update the HEC-2 computer model to 1995 conditions. The measured stream flow data was used to calibrate the HEC-2 model by comparing measured and modelled water surface elevations. Table 5 provides selected calibration results for one of the study areas at the White Clay Creek at Newark. The calibration results indicate the difference between measured and modelled water surface elevations is satisfactorily less than 0.4 feet. This indicates the calibrated HEC-2 model can predict 7Q10 flow depth, velocity, and wetted perimeter with reasonable precision.

2.9 PUBLIC PARTICIPATION

During the course of the Phase One-7Q10 assessment, three public briefings were held at Clayton Hall, University of Delaware for the benefit of interested citizens. Each was held in the afternoon following the Joint Task Force morning session and provided an opportunity for interchange between the Task Force members and the public. The initial session was held on September 12, 1994, where copies of the Scope of Study were distributed for review and comment.

The second briefing took place on January 11, 1995, where a detailed presentation was made regarding the utilization of the HEC2 model and handouts were made available for public discussion regarding the study methodology.

A final briefing was conducted on June 20, 1995 in conjunction with the Joint Task Force meeting on the same date where the final report was presented to the public. The conclusions and recommendations were discussed in detail, including the proposed Phase Two study.

SCHEDULE OF ACTIVITIES

September 12, 1994	-	Initial meeting of Joint Task Force Public Briefing
October 28, 1994	-	Joint Task Force meeting Field Trip
November 10, 1994	-	Joint Task Force meeting
January 11, 1995	-	Joint Task Force meeting Public Briefing
March 10, 1995	-	Field Survey for additional stream cross-sections
April 13, 1995	-	Joint Task Force meeting
June 20, 1995	-	Joint Task Force meeting - Public Briefing

Additionally, the Study Coordinating Group met in whole or in part on 20 occasions during the study period.

TABLE 1
WATER SUPPLY WITHDRAWALS IN THE CHRISTINA RIVER BASIN IN DELAWARE
INSTREAM FLOW NEEDS ANALYSIS

New Castle County, Delaware

No.	Supply Source/ Purveyor	Location	Facility Source	Facility Source Pumping Capacity GPM	MGD	DNREC Allocation Mil. Gal. Per Day	Month	Latitude	Longitude
	RED CLAY CREEK							*To be inserted*	
1	NVF	Yorklyn	2 Intakes	4,490	3.50	3.50	96.00	*during phase 2*	
2	Hercules Research Ctr.	Woodale	1 Intake	625	0.90	0.90	22.00		
3	Hercules C.C.	Woodale	1 Intake	350	0.50	0.50	5.00		
4	Samuel Beard	Wilmington	1 Intake	100	0.03	0.03	0.93		
	CHRISTINA RIVER								
5	Marvin Hershberger	Smalleys Pond, Hdwtrs.	1 Intake	60	0.02	0.02	0.35		
6	Cavalier's C.C.	Newark, Pond #1, River	1 Intake	1,400	0.59	0.59	8.15		
7	Wilmington Suburban	Smalley's Pond	Christina WTP	4,165	6.00	---	---		
8	Ed Oliver C.C.	Wilmington, Pond #1	1 Intake	1,250	0.45	0.45	8.00		
	BRANDYWINE RIVER								
9	Wilmington Finishing	Wilmington	Intake #1 & #2	3,600	1.00	1.00	25.00		
10	Dupont C.C.	Wilmington	1 Intake	550	0.36	0.36	11.00		
11	Dupont C.C.	Wilmington	1 Intake	250	0.36	0.36	11.00		
12	Wilmington C.C.	Kennett Pike	1 Intake	1,800	1.30	1.30	24.40		
13	Wilmington C.C.	Kennett Pike	1 Intake	300	0.43	---	---		
14	Wilmington C.C.	Kennett Pike	1 Intake	50	---	---	---		
15	Brandywine C.C.	Shipley Rd., Pond #1	1 Intake	500	0.51	0.51	7.00		
16	City of Wilmington	Brandywine WTP	Brandywine P.S.	13,890	20.00	---	---		
17	City of Wilmington	Porter WTP	Wills P.S.	16,670	24.00	---	---		
	WHITE CLAY CREEK								
18	Curtis Paper	Newark	1 Intake	---	1.00	---	---		
19	NVF	Newark	1 Intake	4,500	1.50	1.50	35.00		
20	E.I. Dupont	Louviers	1 Intake	---	0.29	---	---		
21	Dupont C.C.	Louviers Golf Course	1 Intake	700	0.23	0.23	6.75		
22	Delcastle Golf Club	McKennans Church Rd.	1 Intake	750	0.26	0.26	5.20		
23	Three Little Bakers C.C.	Wilmington	1 Intake	1,000	0.24	0.24	7.20		
24	Wilmington Suburban	Red & White Clay Cr.	Stanton WTP	20,835	30.00	---	---		
25	City of Newark	Paper Mill Rd. WTP	Newark WTP	3,500	5.00	5.00	15.00		
					98.47				

Source: Delaware Department of Natural Resources and Environmental Control, (DNREC), Division of Water Resources (1994).

TABLE 2
7Q10 DISCHARGE AND MAXIMUM WITHDRAWAL CAPACITY
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Stream	Purveyor	7Q10* (mgd)	Max. Withdrawal** Pumping Capacity (mgd)
Brandywine Creek at City Dam	Wilmington WTP	49.31	44
Christina River at Smalley's Pond	United Water Delaware Christiana WTP	2.09	6
White Clay Creek at Newark	City of Newark, Paper Mill WTP	7.27	5***
White Clay Creek at Stanton	United Water Delaware Stanton WTP	17.20	30
			Total = 85 mgd

References:
* Churchman's EIS, Volume I, Metcalf and Eddy, October 1991.
** Delaware DNREC, Division of Water Resources, 1994.
*** Existing Pumping Capacity = 3 mgd, Future Capacity = 5 mgd

TABLE 3A
GENERAL DEPTH, VELOCITY, AND SUBSTRATE HABITAT CRITERIA
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Species	Source	Depth		Velocity		Substrate inch (cm)	Fish Size inch (mm)	Remarks
		meter	feet	cm/sec	ft/sec			
Rainbow Trout (S. gairdneri)	Bovee, 1975	0.31-1.2	1.02-3.94	5-40	0.16-1.31	0.20-1.96 (0.5-5)	—	——
Brown Trout	Bovee, 1975	0.31-1.2	1.02-3.94	5-40	0.16-1.31	0.20-1.96 (0.5-5)	—	——
Red Breast Sunfish (Lepomis auritus)	S.C. Wildlife and Marine Resource Dept.	0.3	1					
Black Bullhead (I. mellas)	Bovee, 1975	0.31-2.5	1.02-8.20	0-0.5	0.00-0.016	0.02 (0.05)	—	——
Channel Catfish (I. punctatus)	Bovee,1975	0.31-1.5	1.02-4.92	5-40	0.16-1.31	0.20-1.96 (0.5-5)	—	——
Smallmouth Bass (M. dolomieui)	Bovee, 1975	0.31-1.2	1.02-3.94	5-40	0.16-1.31	0.20-1.96 (0.5-5)	—	——
Rock Bass (A. rupestris)	Bovee, 1975	0.61-1.2	2.00-3.94	5-40	0.16-1.31	0.20-1.96 (0.5-5)	—	——
White Perch								
White Sucker (C. commersoni)	Bovee, 1975	0.15-2.5	0.49-8.20	0.5-150	0.016-4.92	0.02-11.8 (0.05-30)		

References:
Bovee, 1975 as cited in Wesche, T.A and R.A. Rechard, 1980 in "Designing and Negotiating Studies Using IFIM", U.S. Fish and Wildlife Service, National Ecology Research Center, Fort Collins, Colorado.

TABLE 3B
GAME FISH LIFE HISTORY
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Species Common Name (Scientific Name)	Source	Distribution	Water warm	Water cool	Water cold	Habitat	Spawning Time	Spawning Temp C (F)	Fecundity (# of eggs)	Egg Incubation Time	Age at Maturation (years)	Size Range kg (lb)
Rainbow Trout (Salmo gairdneri)	Bell, 1973	Cold streams and lakes in U.S.			X	Streams and lakes of varying size	Spring Feb-June	—	1500 Ave	Feb-Aug	3-4	0.11-19.1 (1/4-42)
Brown Trout (Salmo trutta)	Baxter & Simon, 1970, Bell, 1973	Native of Europe; cold U S. lakes and Streams			X	Streams of mnts , foothill and plains; lakes and reservoirs	Sep-Jan	2.7-15.5 (37-60)	1000-1500	Oct-Mar	3-4	0.11-18.1 (1/4-40)
Redbreast Sunfish (Lepomis auritus)												
Smallmouth Bass (Micropterus dolomieui)	Baxter & Simon, 1970; Scott & Crossman, 1973; Bell, 1973	Native to S. Dakota to Georgia, Alabama; introduced to western waters	X			Streams, lakes, reservoirs	Mar-Jul	12.8-20 (55-68)	5000-14,000	4-10 days from spawning	2-3	0.27-2.3 (1/2-5)
Rock Bass (Ambloplites rupestris)	Baxter & Simon, 1970; Scott & Crossman, 1973; Minckley, 1973	From Minitoba through Great Lakes to NY and Oklahoma; intoduced to western waters	X			Streams, lakes, reservoirs	May-Jun	15.5-21.1 (60-70)	3000-11,000	3-4 days from spawning	—	0.06-0 23 (1/8-1/2)
Channel Catfish (Ictalarus punctatus)	Baxter & Simon, 1970; Sigler & Miller, 1963; Bell, 1973	From Canada and Montana through Great Lakes to Florida and N Mexico; introduced throughout N. America	X			Lakes, reservoirs, & streams in areas of moderate current	May-Jul	21.1-29.4 (70-85)	4000-40,000	5-10 days after spawning	5-8	0.11-5.9 (1/4-13)
Black Bullhead (Ictalurus melas)	Baxter & Simon, 1970; Sigler & Miller, 1963; Bell, 1973; Scott & Crossman, 1973	From NY to Rockies, and Minitoba to Tenn.; introduced through S.and W. U.S.	X			Lakes, reservoirs, sluggish streams, ponds	Apr-Jun	18.3-21.1 (65-70)	2000-12,000	5-15 days after spawning	3	0.11-1.4 (1/4-3)
Redear Sunfish (Lepomis microlophus)	K. Buss in McClane, 1974; Baxter & Simon, 1970	From Southern Illinois south to Florida & Texas; introduced into western waters.	X			Lakes, reservoirs, farm ponds	Apr-Jun	20.0-27.7 (68-82)	—	3 days after spawning	—	less than 1 8
White Perch												
White Sucker (C. commersoni)												

Note:
Data obtained from "Designing and Negotiating Studies Using IFIM", U S. Fish and Wildlife Service

TABLE 3C
DEPTH, VELOCITY, AND SUBSTRATE SPAWNING CRITERIA
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Species	Source	Depth meter (feet)	Velocity cm/sec (ft/sec)	Substrate cm (inch)	Fish Size cm (inch)	How and Where Developed	Remarks
Brown Trout (S. trutta)	Smith, 1973	>0.24 (0.80)	20-68 (0.67-2.24)	0.64-7.62 (0.25-3.0) (Hunter, 1973)	---	Tolerance interval; Oregon -- 5 streams with varying hydraulic conditions	115 redds sampled; V at 0.4' from bed
Brown Trout	Hope & Finnel, 1972	---	>46 (1.50)	---	---	Based on velocity versus egg mortality; Colorado -- Fryingpan Rv.	Relates more to egg incubation than spawning; V at 0.6' from surface
Rainbow Trout (S. gairdneri)	Smith, 1973	>0.18 (>0.6)	48-91 (1.60-2.98)	0.64-5.18 (0.25-2.0)	---	Tolerance interval; Oregon -- Deschutes Rv.	51 redds sampled; V at o.4' above bed
Smallmouth Bass (M. dolomieui)	Bovee,1974	0.90-1.80 (2.95-5.90)	11 (0.36)	sand - rubble	---	Estimated from literature review; Northern Great Plains	V estimated from substrate type; little field verification of criterion
Black Bullhead (I. melas)	Bovee, 1974	0.60-1.20 (1.97-3.94)	Still	mud - sand	---	Estimated from literature review; Northern Great Plains	Little field verification of criterion
Redbreast Sunfish (Lepomis auritus)							
White Sucker (C. commersoni)	Bovee, 1974	0.20-0.30 (0.66-0.98)	31-45 (1.02-1.48)	gravel	---	Estimated from literature review; Northern Great Plains	Little field verification of criterion
Channel Catfish							
Rock Bass							
White Perch							
Blue Gill Sunfish							

Note:
Data obtained from "Designing and Negotiating Studies Using IFIM",
U.S. Fish and Wildlife Service.

TABLE 4
HYDRAULIC DATA FOR THE HEC-2 MODEL
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Stream	HEC-2 Data Source	Study Reach (mi)	No. of Sections	Sections per Mile	Mannings "n" Values	No. of Sections		
						pool	riffle	dam pool
Brandywine Creek at Wilmington	FEMA, 1989 Tetra Tech, 1995	1.5	17	11	0.04 - 0.07	2	5	10
Christina River at Smalley's Pond	FEMA, 1989 Tetra Tech, 1995	2.0	14	9	0.03 - 0.09	9	0	5
White Clay Creek at Newark	FEMA, 1989 Tetra Tech, 1995	1.5	22	15	0.03 - 0.09	3	13	6
White Clay Creek at Stanton	FEMA, 1989 United Water Delaware, 1994 Tetra Tech, 1995 Duffield Associates, 1994	2.0	27	14	0.03 - 0.09	25	2	0

TABLE 5
HEC-2 CALIBRATION RESULTS FOR WHITE CLAY CREEK AT NEWARK
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Sec. No.	Calibration Flow (4/19/95)		Water Surface Elevation (ft)		Difference (ft)
	mgd	cfs	measured*	modelled**	
55713	25.0	38.8	63.54	63.14	-0.40
56623	25.0	38.8	64.30	64.58	+0.28
57030	25.0	38.8	64.87	64.65	-0.22
57970	25.0	38.8	66.43	66.54	+0.11

* Flow, velocity, and water surface elevation measured by Tetra-Tech field survey on April 19, 1995.
** Modelled water surface elevations computed using HEC-2.

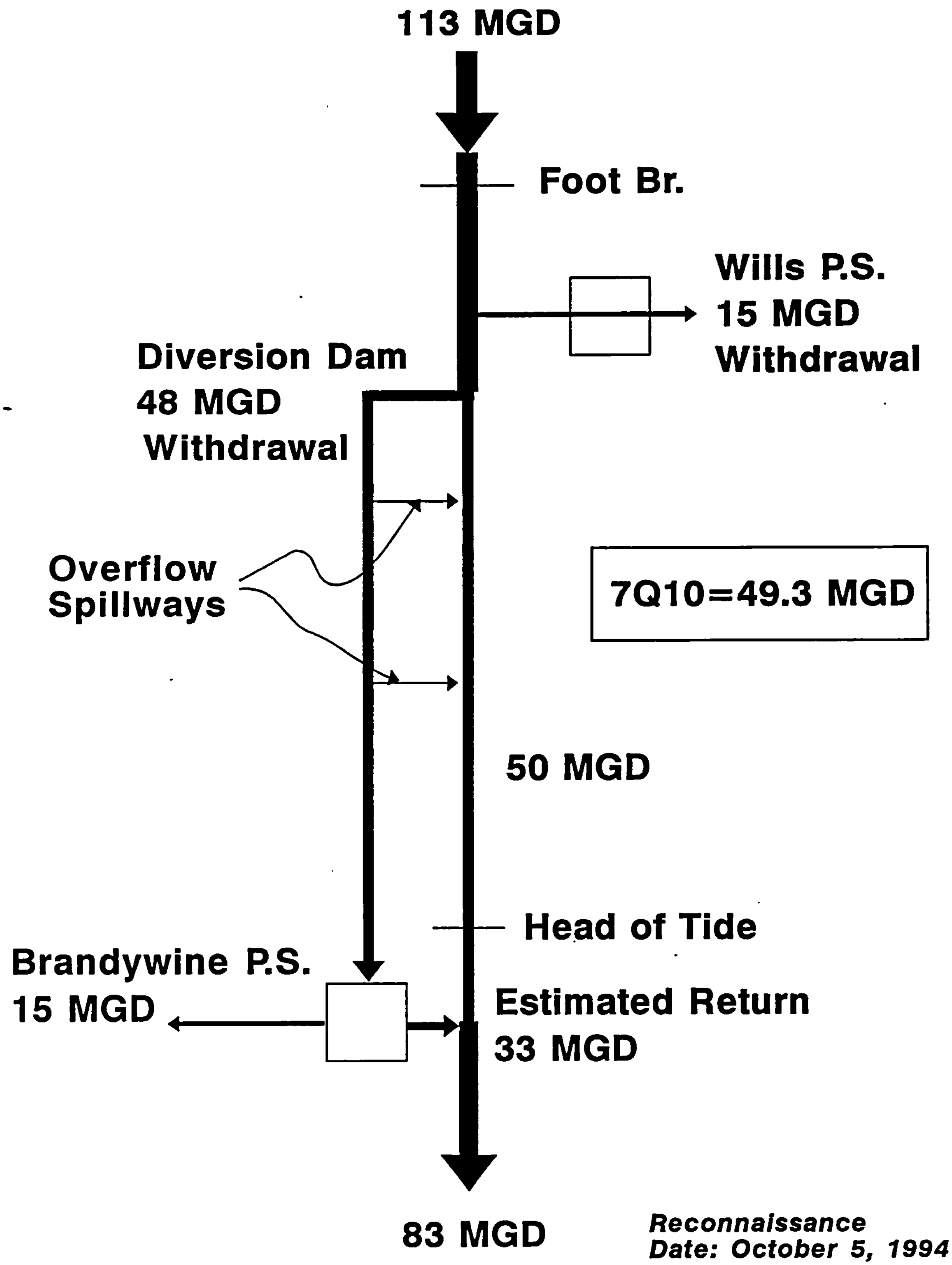


Figure 6. Flow Diagram for Brandywine Creek at Wilmington

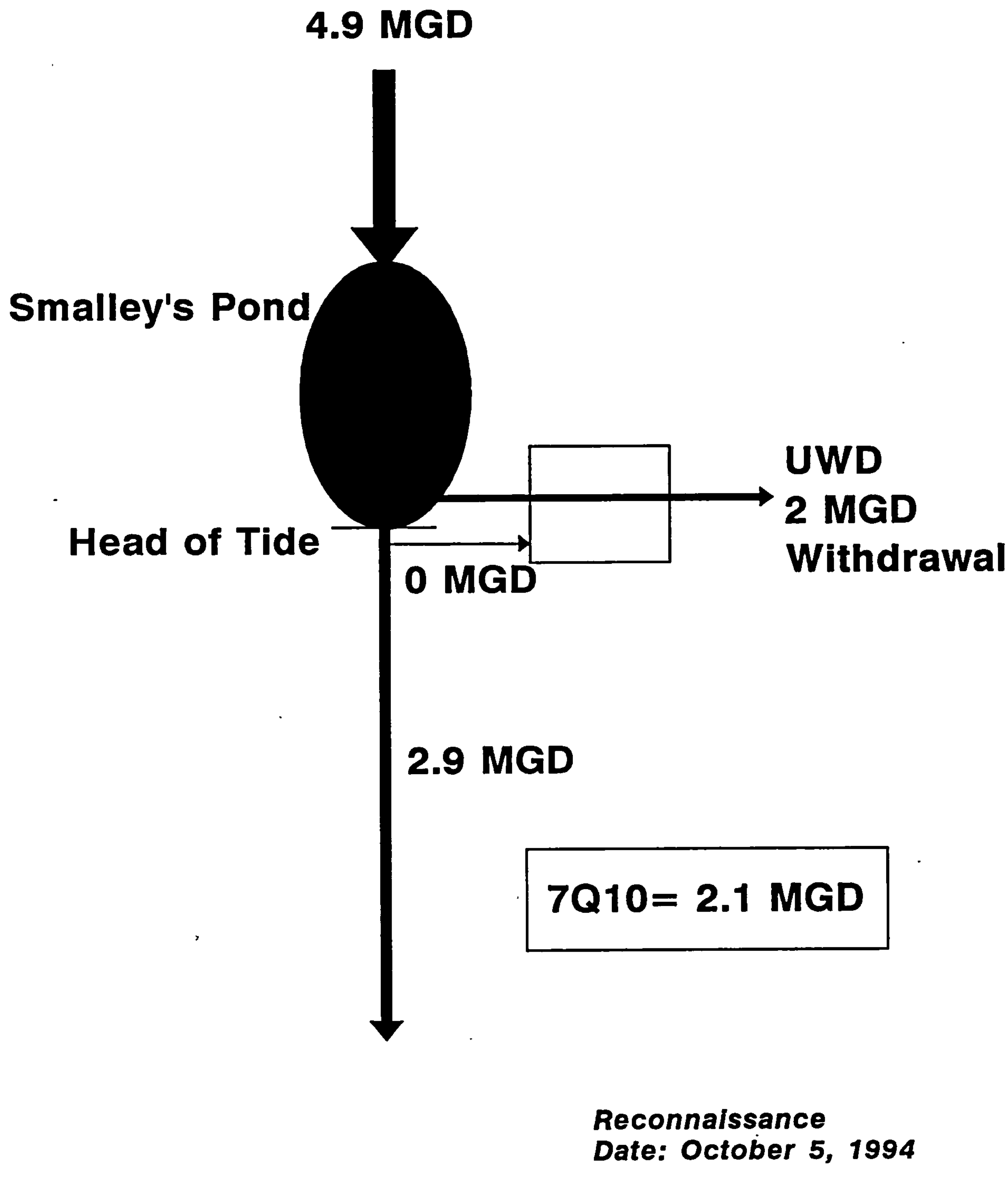


Figure 7. Flow Diagram for Christina River at Smalley's Pond

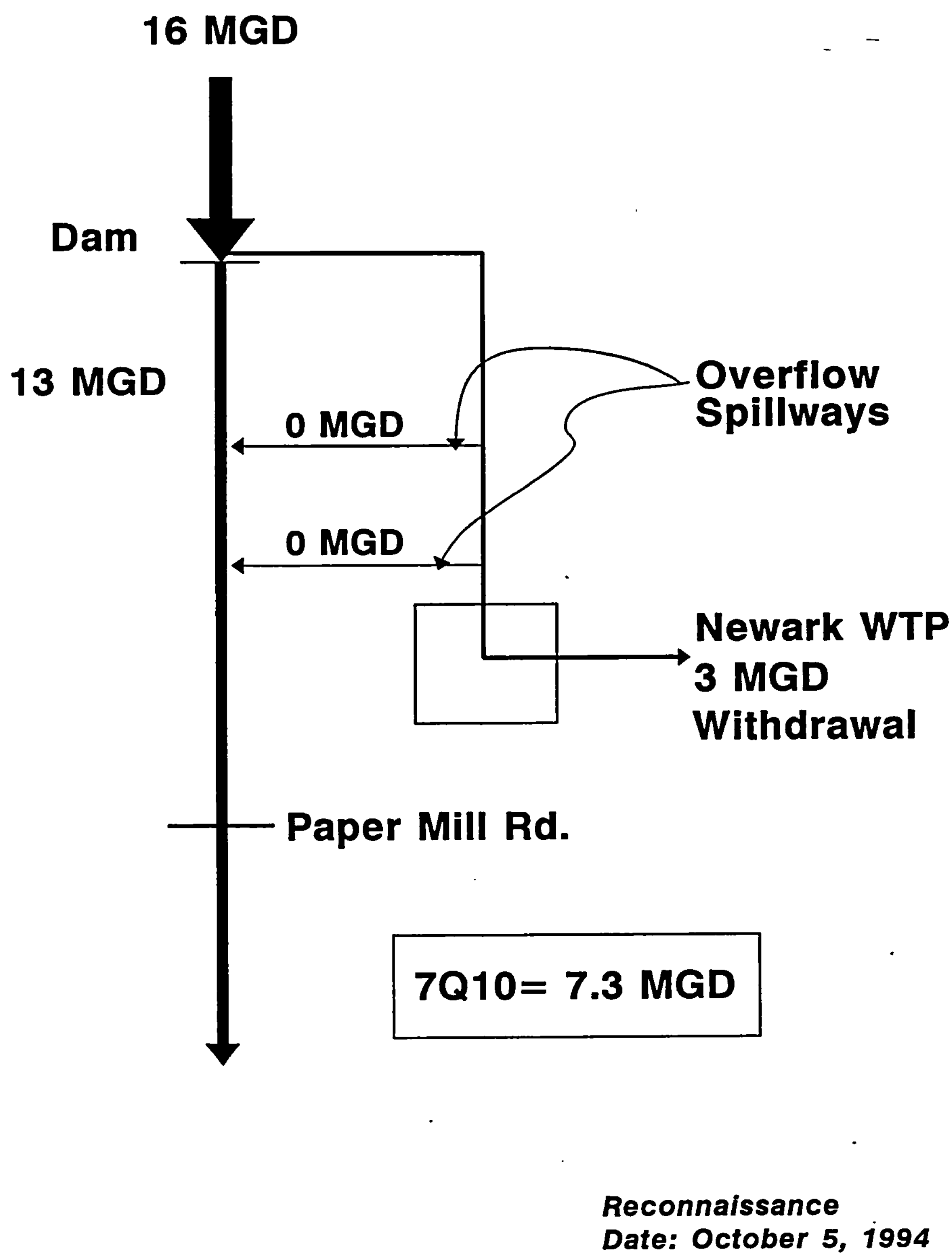


Figure 8. Flow Diagram for White Clay Creek at Newark

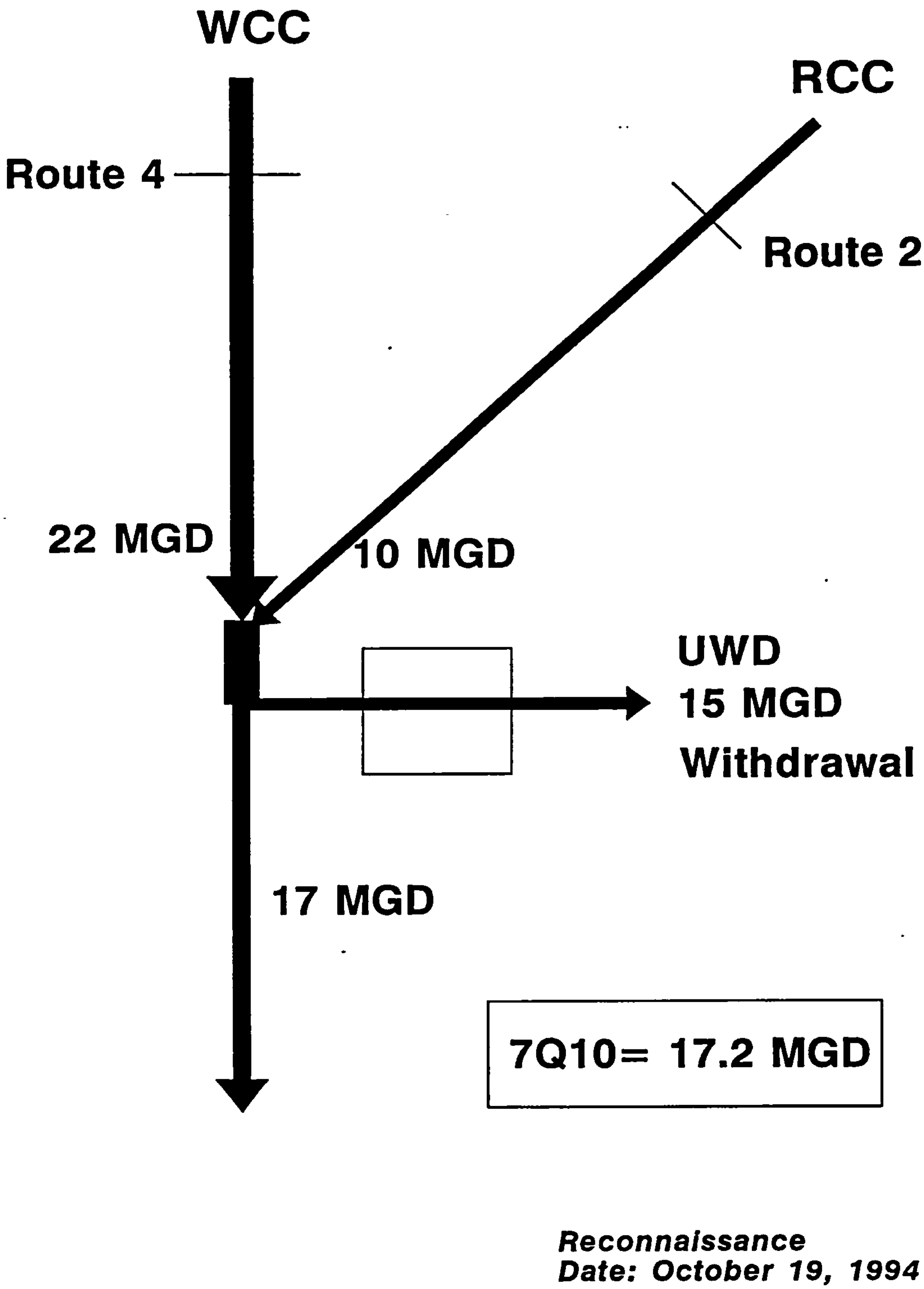


Figure 9. Flow Diagram for White Clay Creek at Stanton

3. RESULTS

The results of the 7Q10 Assessment using the HEC-2 hydraulic model are presented in this section. The HEC-2 model was used to compute flow depth, velocity, and wetted perimeter for the given 7Q10 at each of the four study areas. Wetted perimeter requires additional field work regarding habitat before it can be used as a function of the 7Q10 Assessment. The computed 7Q10 values were then compared to minimum depth and velocity criteria for the selected fish species as cited in Table 3A. The results of the HEC-2 analysis for the 7Q10 are discussed as follows.

1. At all four study areas, a comparison of HEC-2 results to the minimum fish habitat criteria for flow depth and velocity indicate the information provided by Bovee is insufficient to determine the adequacy of the 7Q10 as a minimum flow standard. The results indicate a more intensive literature search regarding habitat needs for the selected species and a field inventory of existing fish habitat is needed before the Joint Task Force can evaluate the adequacy of the 7Q10 as a flow standard.

2. The HEC-2 results indicate the available information is insufficient to evaluate the 7Q10 as a minimum flow stand considering this flow value is cited as the minimum for waste assimilation and chronic aquatic toxicity criterion according to the State of Delaware Surface Water Quality Standards. Additional water quality analysis regarding the 7Q10 as a minimum flow standard is needed during a future phase of work.

3.1 BRANDYWINE CREEK AT WILMINGTON

1. The calibrated HEC-2 model for the Brandywine Creek accurately simulates the flow depth, velocity, and wetted perimeter for the given 7Q10 = 49.3 mgd. The HEC-2 results are listed in Table 6.

2. The head of tide is the dam just downstream from Baynard Boulevard.

3. Review of the stream profile in Figure 10 indicates the 7Q10 flow exceeds a depth of one foot along 87% of the study reach at low tide.

4. 7Q10 depths are less than one foot along the riffle sections just downstream from the dam near Baynard Boulevard and just downstream from City Dam. The critical stream reach with the lowest flow depth is just

downstream from the withdrawal raceway at City Dam.

5. 7Q10 flow depths exceed one foot in the pools created by the dams.

6. A comparison of flow scenarios for a typical stream transect (Section 2.55) indicates the difference between 7Q10 (49.3 mgd) and 7Q50 (37.8 mgd) depth and velocity is 0.09 feet and 0.23 feet per second, respectively (Table 10).

7. The fish habitat tables in Table 3A indicate the flow depth criteria for the selected fish species including Smallmouth Bass and Rock Bass range from 1 to 4 feet and 2 to 4 feet, respectively. However, the Joint Task Force found that additional fish habitat and water quality data are needed along the Brandywine Creek to evaluate the adequacy of the 7Q10 as a minimum flow standard to protect the fishery and provide sufficient water supply.

8. The Flow Exceedance Curve in Figure 19 indicates the flow along the Brandywine Creek will be less than the 7Q10 (49.3 mgd) approximately 2% of the time. The flow will be less than the 7Q10 plus maximum withdrawal (93.3 mgd) 10% of the time.

9. The raceway canal frequently withdraws more flow than needed for water supply purposes. Excess flow in the raceway is diverted back to the creek via side-flow spillways. A means of daily diversion flow control should be evaluated during a future Phase II - 7Q10 Habitat Assessment.

3.2 CHRISTINA RIVER AT SMALLEY'S POND

1. The calibrated HEC-2 model for the Christina River accurately simulates the flow depth, velocity, and wetted perimeter for the given 7Q10 = 2.1 mgd. The HEC-2 results are listed in Table 7.

2. The head of tide along the Christina River is the Smalley's Pond Dam. The 7Q10 water surface elevations were computed for the critical low-flow period which is low tide.

3. The 7Q10 flow exceeds a depth of one foot along 98% of the study reach at low tide. Reaches which exceed a one foot depth include the tidal area downstream from the impoundment created by the Smalley's Pond Dam.

4. Comparison of flow scenarios for Section 59926 indicate the difference

between 7Q10 (2.1 mgd) and 7Q50 (1.1 mgd) depth, and velocity is 0.0 feet and 0.05 feet per second, respectively (Table 11).

5. The fish habitat tables in Table 3A indicate the minimum flow depth criteria for selected fish species including Rainbow Trout, Red Breast Sunfish, and Catfish species range from 1.0 to 4.0 feet. The Joint Task Force was unsuccessful in locating published literature values for the White Perch. However, the Joint Task Force found that additional fish habitat and water quality data is needed along the Christina River to evaluate the adequacy of the 7Q10 as a minimum flow standard to protect the fishery and provide sufficient water supply.

6. The Flow Exceedance Curve in Figure 20 indicates the flow along the Christina River will be less than the 7Q10 (2.1 mgd) approximately 2% of the time. The flow will be less than the 7Q10 plus maximum withdrawal (8.1 mgd) 15% of the time.

3.3 WHITE CLAY CREEK AT NEWARK

1. The calibrated HEC-2 model for the White Clay Creek at Newark accurately simulates the flow depth, velocity, and wetted perimeter for the given 7Q10 = 7.3 mgd. The HEC-2 results are listed in Table 8.

2. The 7Q10 flow exceeds a depth of one foot along 75% of the study reach (Figure 14).

3. The 7Q10 flow exceeds one foot within the pools created by the 3 dams in the study area.

4. Flow depths are less than one foot along the riffle sections just downstream from the small dams within the study reach.

5. A comparison of flow scenarios for the White Clay Creek at Newark indicates the difference between 7Q10 (7.3 mgd) and 7Q50 (4.3 mgd) flow depth and velocity is 0.16 feet and 0.10 feet per second, respectively (Table 12).

6. The fish habitat tables indicated the flow depth criteria for the selected fish species including Rainbow and Brown Trout range from 1 to 4 feet. However, the Joint Task Force found that additional fish habitat and water quality data is needed along the White Clay Creek to evaluate the adequacy of the 7Q10 as a minimum flow standard to protect the fishery and provide

sufficient water supply.

7. The Flow Exceedance Curve (Figure 21) indicates the flow along the White Clay Creek at Newark will be less than the 7Q10 (7.3 mgd) approximately 2% of the time (7 days per year). The flow will be less than the required minimum DRBC passby (14 mgd) approximately 10% of the time. The flow will be less than the DRBC Passby flow plus existing withdrawal (17 mgd) 15% of the time.

8. An engineered means of flow control and metering at the division raceway to the Newark Water Treatment Plant should be evaluated during a future Phase II - 7Q10 Habitat Assessment.

3.4 WHITE CLAY CREEK AT STANTON

1. The calibrated HEC-2 model for the White Clay Creek at Stanton accurately simulates the flow depth, velocity, and wetted perimeter during tidal conditions for the given 7Q10 = 17.2 mgd. The HEC-2 results are summarized in Table 9.

2. Under normal conditions, the head of the tide along the White Clay Creek in the study area extends to the mouth of the Red Clay Creek just upstream from the Stanton WTP intake.

3. 7Q10 water surface elevations were calculated for the most critical stream flow conditions which is low tide (elevation at the mouth of the White Clay Creek = -1.53 feet, Figure 16).

4. The 7Q10 flow exceeds a depth of one foot along 90% of the study reach during low tide (Figure 17). The 7Q10 flow exceeds a depth of one foot along 100% of the study reach during high tide.

5. The 7Q10 depth at low tide is less than one foot near the mouth of Churchmans Marsh and along a riffle section just downstream from the intake near the AMTRAK Bridge. During slack and high tide conditions (20 hours per day), the 7Q10 flow depth exceeds one foot along the entire study reach.

6. Comparison of flow scenarios for Section 13843 indicates the difference between the 7Q10 (17.2 mgd) and 7Q50 (11.2 mgd) depth and velocity is 0.16 feet and 0.06 feet per second, respectively (Table 13).

7. The fish habitat table indicates the flow depth criteria for the selected Catfish species range from 1 to 4 feet. The Joint Task Force was unsuccessful in locating literative values for the White Perch which is a tidal species. Additional fish habitat and water quality data during a Phase II - 7Q10 Assessment is needed along the tidal reach of the White Clay Creek to evaluate the adequacy of the 7Q10 as a minimum stream flow protection standard.

8. The Flow Exceedance Curve (Figure 22) indicates the flow along the White Clay Creek at Stanton will be less than the 7Q10 approximately 2% of the time (about 7 days per year). The flow will be less than the 7Q10 plus maximum withdrawal (47.2 mgd) 20% of the time.

TABLE 6
HEC-2 RESULTS FOR THE BRANDYWINE CREEK AT WILMINGTON AT 7Q10 INSTREAM FLOW ANALYSIS
New Castle County, Delaware

Section No.	Location	Type of Flow	Min. Channel Elevation (ft)	Water Surface Elevation (ft)	Max. Flow Depth (ft)	Avge. Velocity (fps)	Wetted Perimeter (ft)
2.04	Tidal Area	Pool	-6.00	-1.53	4.47	0.17	130.19
2.38	Head of Tide	Riffle	-0.40	0.46	0.86	3.77	47.18
2.39	Dam #1	Dam Pool	4.60	4.84	0.24	2.77	119.69
2.40	Baynard Blvd.	Dam Pool	1.50	4.97	3.47	0.18	171.81
2.55*	---	Riffle	7.34	8.32	0.98	3.99	38.77
2.65	Van Buren St.	Riffle	12.60	13.77	1.17	1.41	133.78
2.67*	I-95	Riffle	11.02	13.81	2.79	0.24	176.62
2.93*	---	Pool	11.71	13.87	2.16	0.54	109.78
2.94	---	Riffle	13.20	14.12	0.92	4.42	29.03
2.95	City Dam	Dam Pool	23.30	23.52	0.22	2.67	129.02
2.96	Raceway Intake	Dam Pool	18.30	23.65	5.35	0.11	183.56
2.99*	---	Dam Pool	18.96	23.65	4.69	0.07	177.71
3.05	Footbridge	Dam Pool	23.50	23.66	0.16	2.31	200.05
3.32	---	Dam Pool	24.70	26.22	1.52	1.17	87.99
3.41	---	Dam Pool	24.10	26.34	2.24	0.53	75.38
3.42	---	Dam Pool	33.50	33.80	0.30	3.00	92.58
3.43	---	Dam Pool	26.00	33.96	7.96	0.08	230.80

Notes:
(1) Results presented for 7Q10 flow = 76.28 cfs = 49.3 mgd.
(2) Starting water surface elevation computed at low tide = -1.53 ft (NGVD).
(3) Elevations based on NGVD of 1929.
* Cross-sections field surveyed by Tetra-Tech on April 20,1995.

TABLE 7
HEC-2 RESULTS FOR THE CHRISTINA RIVER AT SMALLEY'S POND AT 7Q10
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Section No.	Location	Type of Flow	Min. Channel Elevation (ft)	Water Surface Elev. (ft)	Max Flow Depth (ft)	Avge. Velocity (fps)	Wetted Perimeter (ft)
55764	Rte 273	Pool	-2.00	-1.53	0.47	0.15	46.42
56750	---	Pool	0.10	2.10	2.00	0.03	48.64
58500	---	Pool	0.50	2.10	1.60	0.03	77.02
58915	Smalley's Dam Rd.	Pool	0.60	2.10	1.50	0.04	75.96
58982	---	Pool	0.60	2.10	1.50	0.09	35.53
59032	---	Pool	0.60	2.10	1.50	0.09	35.53
59207*	---	Pool	-0.20	2.10	2.30	0.07	40.22
59926*	---	Pool	0.46	2.10	1.64	0.10	33.19
60440	Head of Tide	Pool	-1.20	2.10	3.30	0.01	155.69
60530	Smalley's Pond Dam (Intake to WTP)	Dam Pool	9.80	9.82	0.02	0.81	199.01
60805	---	Dam Pool	6.40	9.83	3.43	0.00	484.30
61700	Smalley's Pond	Dam Pool	2.40	9.83	7.43	0.00	327.20
63850	---	Dam Pool	3.10	9.83	6.73	0.02	57.70
66990	---	Dam Pool	6.00	9.83	3.83	0.02	54.73

(1) Results presented for 7Q10 flow = 3.23 cfs = 2.1 mgd.
(2) Starting water surface elevation computed at low tide = -1.53 ft (NGVD).
(3) Elevations based on NGVD of 1929.
* Cross-sections field surveyed by Tetra-Tech on April 18, 1995.

TABLE 8
HEC-2 RESULTS FOR THE WHITE CLAY CREEK AT NEWARK AT 7Q10
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Section No.	Location	Type of Flow	Min. Channel Elevation (ft)	Water Surface Elevation (ft)	Max. Flow Depth (ft)	Avge. Velocity (fps)	Wetted Perimeter (ft)
49000	---	Riffle	45.70	46.70	1.00	0.46	35.09
50000	---	Riffle	47.40	48.01	0.61	2.65	20.63
50055	Dam	Riffle	52.00	52.34	0.34	2.35	28.36
50090	---	Dam Pool	49.70	52.45	2.75	0.07	70.33
52045	---	Dam Pool	50.80	52.46	1.66	0.28	33.20
52855	---	Riffle	52.60	53.11	0.51	2.91	15.21
53155	Paper Mill Rd.	Riffle	55.60	56.34	0.74	1.42	19.35
53205	---	Riffle	55.80	56.56	0.76	1.34	19.78
53244	---	Riffle	55.80	56.57	0.77	3.93	7.46
53280	---	Riffle	56.20	56.91	0.71	0.32	86.04
53320	Dam at Gage	Riffle	62.40	62.47	0.07	1.47	116.31
53345	---	Dam Pool	56.20	62.51	6.31	0.01	164.14
55360	---	Dam Pool	60.20	62.51	2.31	0.10	69.01
55713*	Creek Rd.	Riffle	62.58	62.97	0.39	2.07	38.00
56623*	---	Pool	62.57	63.87	1.30	0.50	30.29
57000	---	Pool	62.50	63.92	1.42	0.26	48.96
57030*	---	Riffle	63.66	63.97	0.31	2.69	18.91
57970*	---	Riffle	65.26	66.18	0.92	0.61	37.69
58305	---	Pool	64.40	66.19	1.79	0.14	71.36
58345	Dam at Raceway	Riffle	74.50	74.67	0.17	1.72	72.25
58375	Intake to WTP	Dam Pool	71.00	74.73	3.73	0.05	106.83
60120	---	Dam Pool	72.10	74.73	2.63	0.12	56.58

Notes:
(1) Results presented for 7Q10 flow = 11.27 cfs = 7.3 mgd.
(2) Elevations based on NGVD of 1929.
* Cross-sections field surveyed by Tetra-Tech on April 19,1995.

TABLE 9
HEC-2 RESULTS FOR THE WHITE CLAY CREEK AT STANTON AT 7Q10
INSTREAM FLOW NEEDS ANALYSIS
New Castle County, Delaware

Section No.	Location	Type of Flow	Min. Channel Elevation (ft)	Water Surface Elevation (ft)	Max Flow Depth (ft)	Avge. Velocity (ft)	Wetted Perimeter (ft)
2600	---	Tidal Pool	-5.50	-1.53	3.97	0.06	120.82
5050	Churchman's Marsh	Tidal Pool	-1.60	-1.18	0.42	2.56	52.91
5425	---	Tidal Pool	-1.60	-0.66	0.94	0.51	98.66
6200	---	Tidal Pool	-5.17	-0.58	4.59	0.25	117.22
7900	---	Tidal Pool	-2.60	-0.49	2.11	0.43	59.12
9800	---	Tidal Pool	-1.40	-0.27	1.13	0.24	99.53
10800	---	Tidal Pool	-1.10	-0.20	0.90	1.12	36.77
10900	---	Tidal Pool	-1.70	0.34	2.04	0.65	43.04
11436	---	Tidal Pool	-2.10	0.45	2.55	0.58	40.43
12320	---	Tidal Pool	-1.15	0.68	1.83	0.47	62.01
12560	---	Tidal Pool	-1.33	0.71	2.04	0.10	146.04
12660	AMTRAK Bridge	Tidal Pool	-1.30	0.71	2.01	0.20	82.01
12703	---	Tidal Pool	-1.30	0.71	2.01	0.20	82.00
12753	---	Tidal Pool	-1.30	0.71	2.01	0.20	82.00
12873	---	Tidal Pool	-0.66	0.70	1.36	0.99	39.29
13843	Stanton WTP	Riffle	1.60	2.56	0.96	0.97	57.01
13955	Head of Tide	Pool	0.30	2.66	2.36	0.29	50.46
14073	Confl. w/ RCC	Riffle	1.71	2.56	0.85	3.76	16.56
14990	---	Pool	3.01	4.75	1.74	0.94	28.87
15890	Old Rte. 7 Bridge	Pool	2.50	4.81	2.31	0.20	70.79
15940	---	Pool	2.50	4.81	2.31	0.20	70.91
15979	---	Pool	2.50	4.81	2.31	0.20	70.83
16180	Rte. 4 Bypass	Pool	3.10	4.81	1.71	0.35	45.97
16270	---	Pool	3.10	4.81	1.71	0.35	45.97
16380	---	Pool	3.10	4.82	1.72	0.34	45.97
16430	---	Pool	3.10	4.82	1.72	0.34	45.98
17000	---	Pool	3.10	4.84	1.74	0.28	55.80

Notes:
(1) Results presented for 7Q10 flow = 26.6cfs = 17.2 mgd.
(2) Starting water surface elevation computed at low tide = -1.53 ft (NGVD).
(3) Elevations based on NGVD of 1929.

TABLE 10
SECTION 2.55 FLOW SCENARIOS ALONG BRANDYWINE CREEK AT WILMINGTON

INSTREAM FLOW NEEDS ANALYSIS

New Castle County, Delaware

Scenario	Flow (cfs)	Flow (mgd)	Depth (ft)	Velocity (fps)	Wetted Perimeter (ft)
1. 1948 Drought*	30.0	19.4	0.71	3.17	31.64
2. 10% of Mean Annual Flow*	46.1	29.8	0.83	3.40	36.21
3. 7Q50**	58.5	37.8	0.89	3.76	37.16
4. 7Q20**	67.2	43.5	0.93	3.89	37.96
5. 7Q10**	76.3	49.3	0.98	3.99	38.77
6. 20% of Mean Annual Flow*	92.2	59.6	1.05	4.26	39.89
7. 7Q10 plus Max. Withdrawal**	144.4	93.3	1.25	4.80	43.41
8. 40% of Mean Annual Flow*	184.4	119.2	1.40	4.98	46.09

References:
* Water Resouces Data, Maryland and Delaware, USGS, WY 1993.
** Churchman's EIS, Volume I, Appendix B, Metcalf & Eddy, Oct 11, 1991.

TABLE 11
SECTION 59926 FLOW SCENARIOS ALONG CHRISTINA RIVER AT SMALLEY'S POND

INSTREAM FLOW NEEDS ANALYSIS

New Castle County, Delaware

Scenario	Flow (cfs)	Flow (mgd)	Depth (ft)	Velocity (fps)	Wetted Perimeter (ft)
1. 1966 Drought*	1.1	0.7	1.64	0.03	33.14
2. 7Q50**	1.6	1.1	1.64	0.05	33.15
3. 7Q20**	2.4	1.5	1.64	0.07	33.16
4. 7Q10**	3.2	2.1	1.64	0.10	33.19
5. 10% of Mean Annual Flow*	6.5	4.2	1.67	0.10	35.23
6. 7Q10 plus Max. Withdrawal**	12.6	8.1	1.85	0.15	38.26
7. 20% of Mean Annual Flow*	12.8	8.3	1.91	0.20	40.69
8. 40% of Mean Annual Flow*	25.7	16.6	2.01	0.21	45.78

References:
* Water Resouces Data, Maryland and Delaware, USGS, WY 1993.
** Churchman's EIS, Volume I, Appendix B, Metcalf & Eddy, Oct 11, 1991.

TABLE 12
SECTION 57970 FLOW SCENARIOS ALONG WHITE CLAY CREEK AT NEWARK

INSTREAM FLOW NEEDS ANALYSIS

New Castle County, Delaware

Scenario	Flow (cfs)	Flow (mgd)	Depth (ft)	Velocity (fps)	Wetted Perimeter (ft)
1. 1966 Drought*	3.6	2.3	0.63	0.42	30.02
2. 7Q50**	6.6	4.3	0.76	0.51	33.82
3. 10% of Mean Annual Flow*	8.8	5.7	0.84	0.56	36.06
4. 7Q20**	9.0	5.8	0.85	0.57	36.23
5. 7Q10**	11.3	7.3	0.92	0.61	37.69
6. 20% of Mean Annual Flow*	17.6	11.4	1.07	0.72	40.66
7. DRBC Passby	21.6	14	1.13	0.80	41.84
8. Passby plus Max. Withdrawal	26.3	17	1.15	0.95	42.2
9. 40% of Mean Annual Flow*	35.3	22.8	1.25	1.10	44.19

References:
* Water Resouces Data, Maryland and Delaware, USGS, WY 1993.
** Churchman's EIS, Volume I, Appendix B, Metcalf & Eddy, Oct 11, 1991.

TABLE 13
SECTION 13843 FLOW SCENARIOS ALONG
WHITE CLAY CREEK AT STANTON

INSTREAM FLOW NEEDS ANALYSIS

New Castle County, Delaware

Scenario	Flow (cfs)	Flow (mgd)	Depth (ft)	Velocity (fps)	Wetted Perimeter (ft)
1. 1966 Drought*	8.8	5.7	0.58	0.90	34.13
2. 7Q50*	17.3	11.2	0.80	0.91	47.58
3. 10% of Mean Annual Flow*	21.0	13.6	0.87	0.94	51.55
4. 7Q20**	22.8	14.7	0.90	0.95	53.47
5. 7Q10**	26.6	17.2	0.96	0.97	57.01
6. 20% of Mean Annual Flow*	42.1	27.2	1.16	1.06	68.56
7. 7Q10 plus Max. Withdrawal**	73.0	47.2	1.43	1.21	83.09
8. 40% of Mean Annual Flow*	84.1	54.4	1.50	1.27	83.35

References:
* Water Resouces Data, Maryland and Delaware, USGS, WY 1993.
** Churchman's EIS, Volume I, Appendix B, Metcalf & Eddy, Oct 11, 1991.

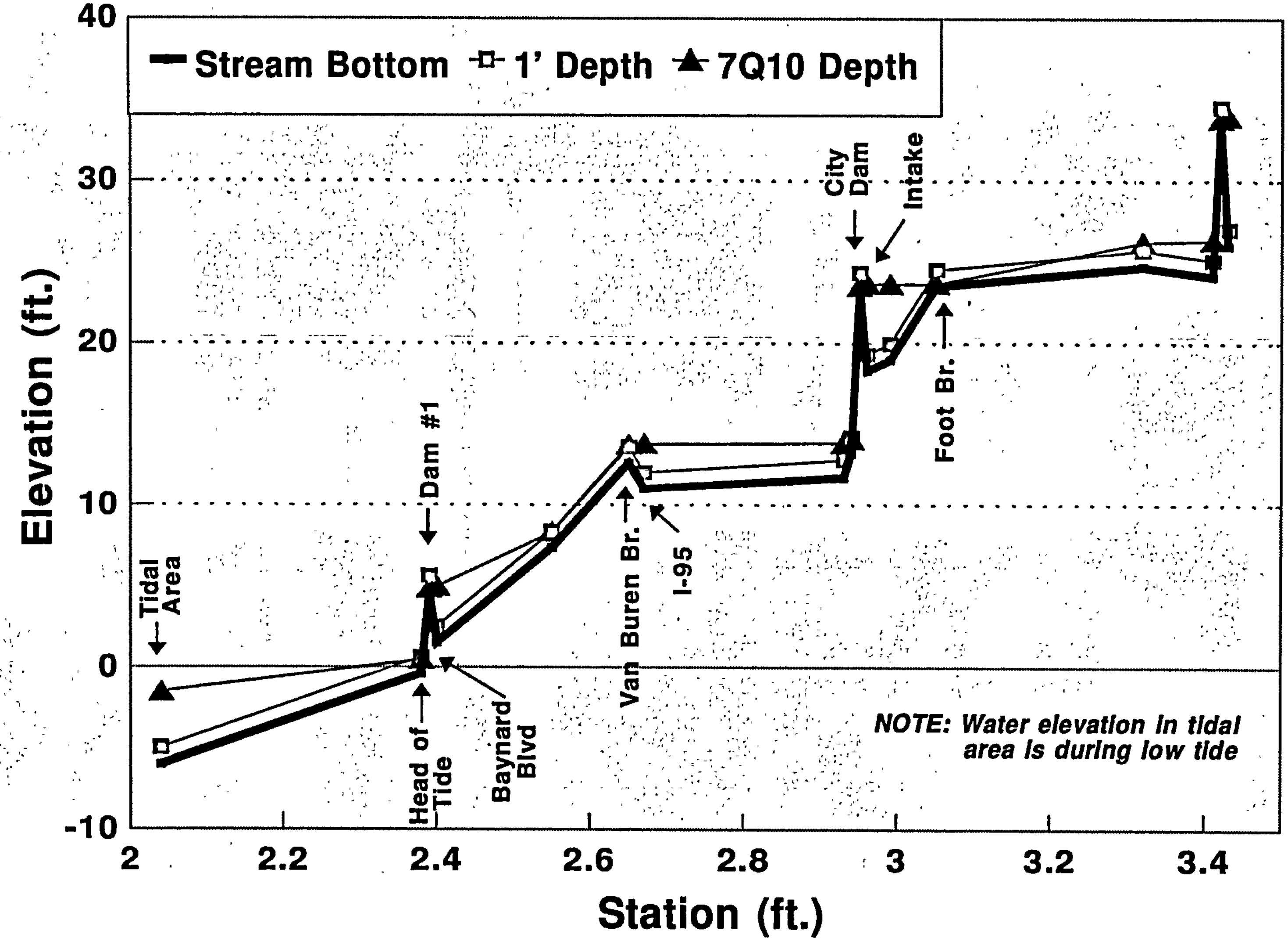
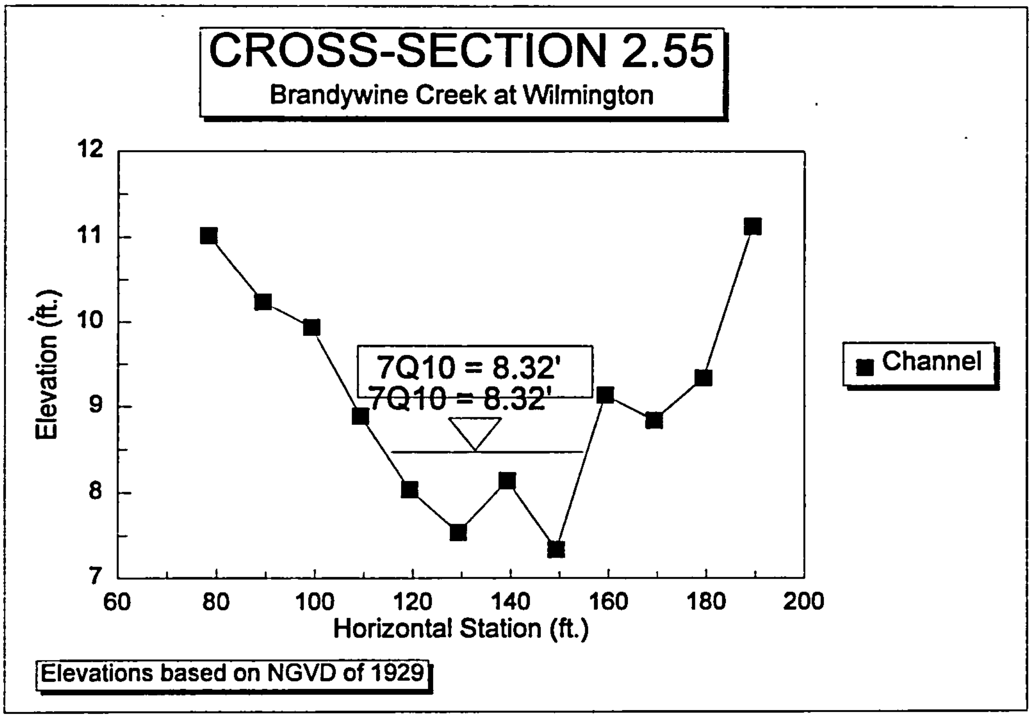


Figure 10. Stream Profile Along Brandywine Creek at Wilmington



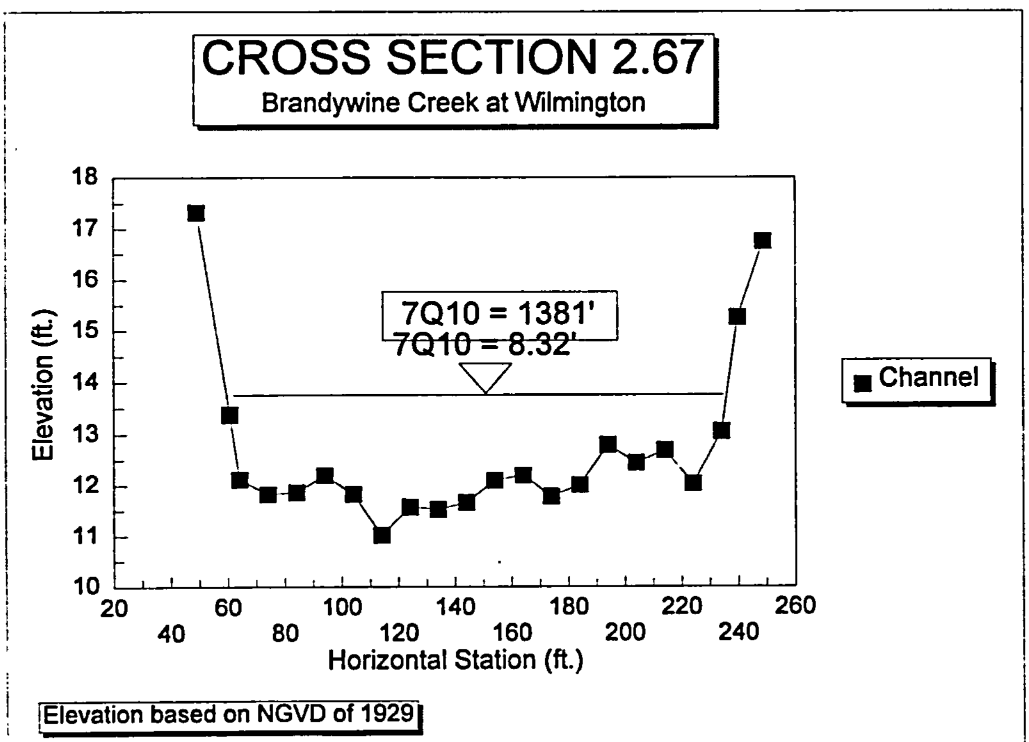


Figure 11. Cross-Sections 2.55 and 2.67 along Brandywine Creek at Wilmington

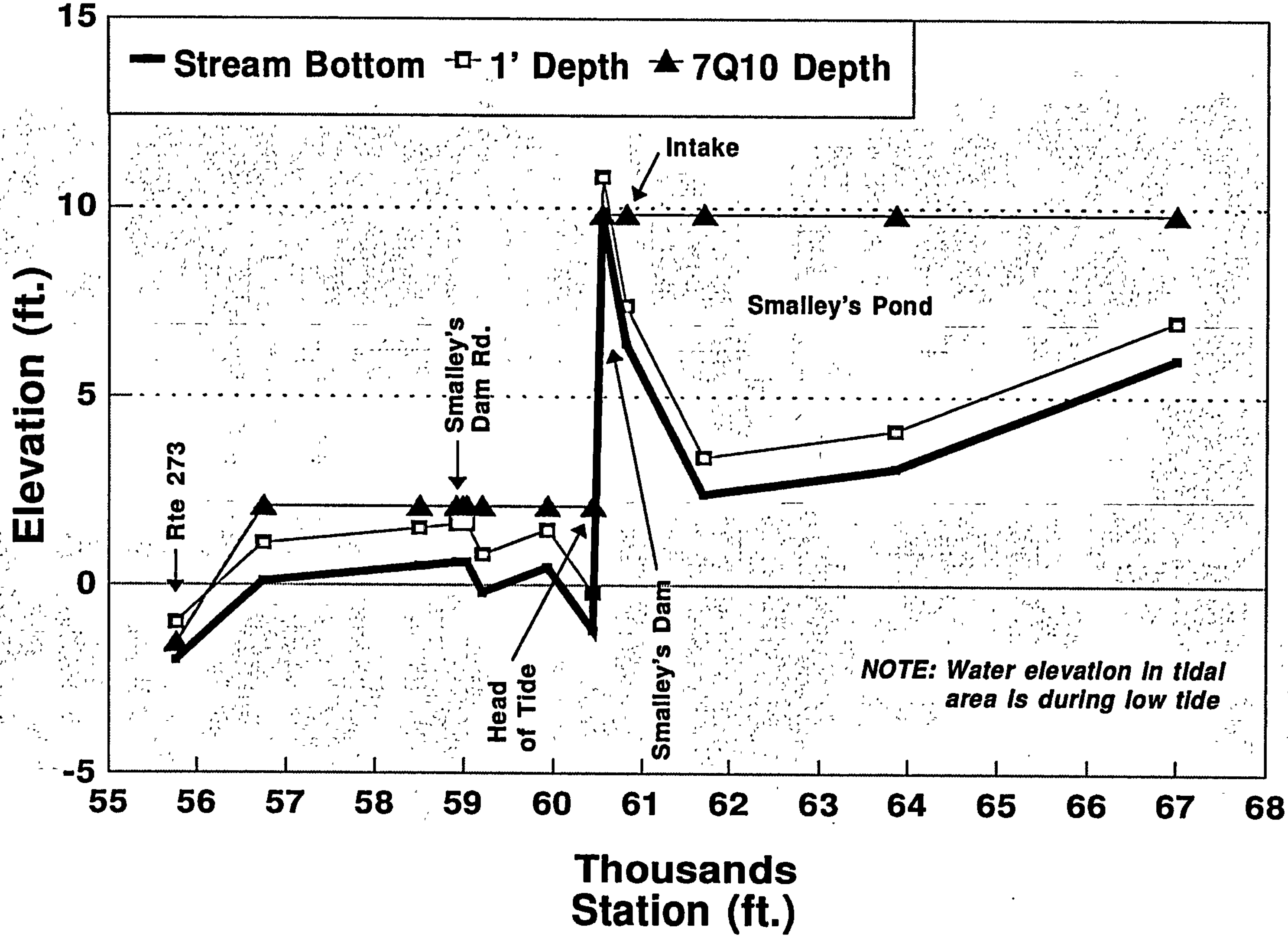
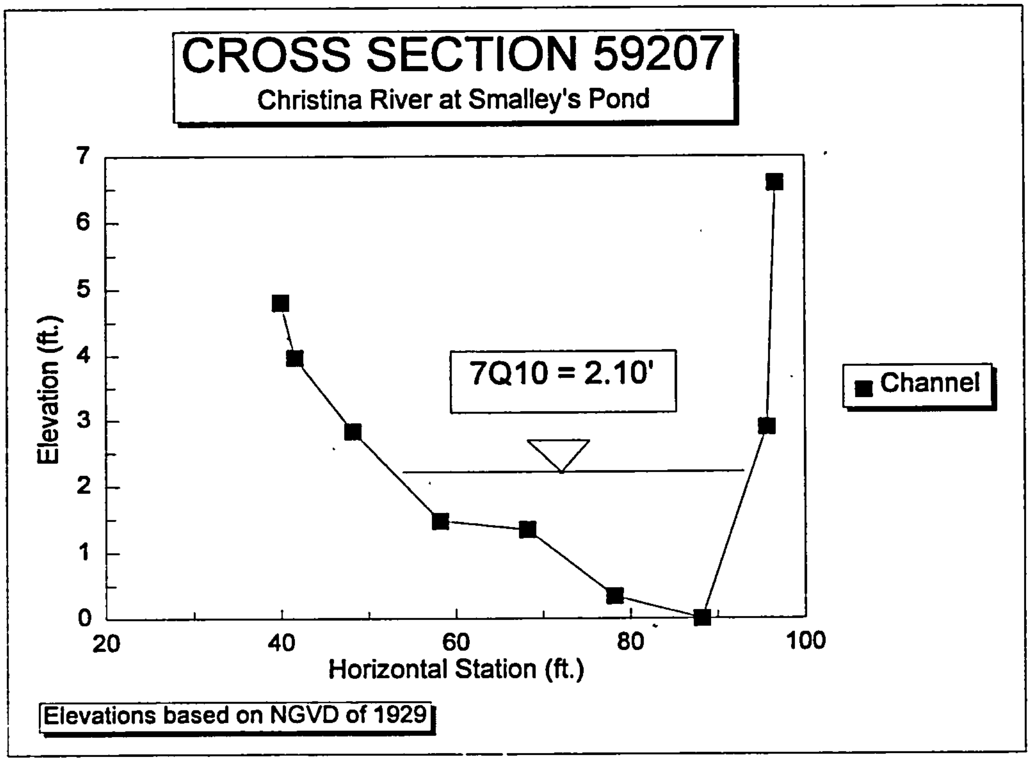


Figure 12. Stream Profile Along Christina River at Smalley's Pond



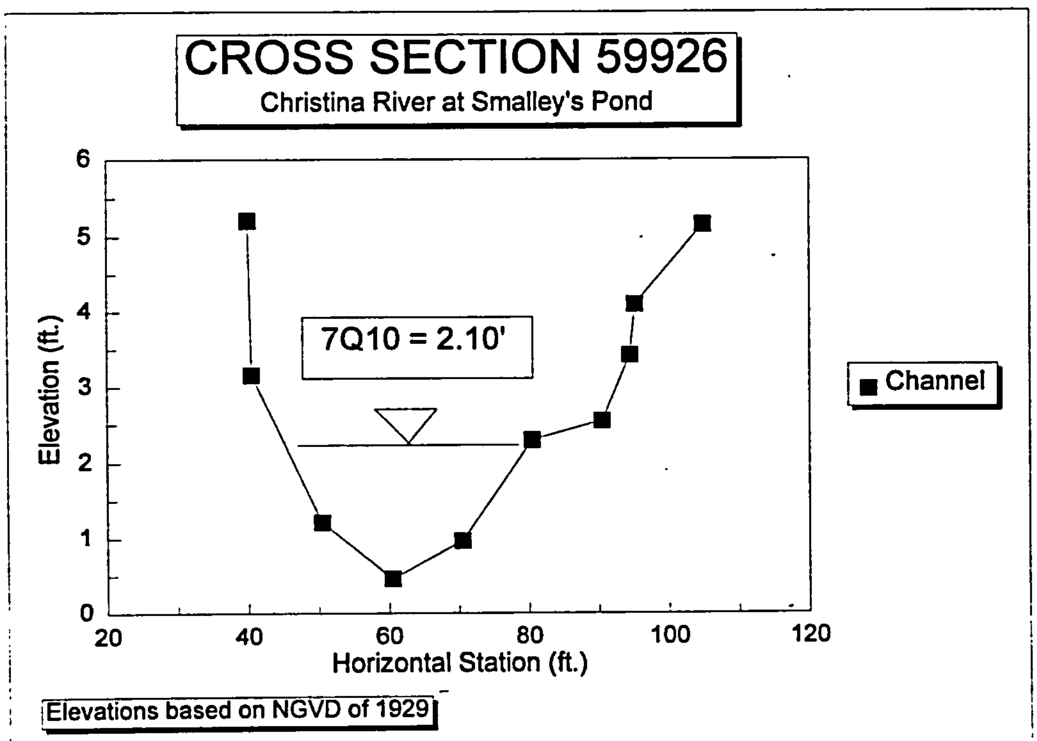


Figure 13. Cross-Sections 59207 and 59926 along Christina River at Smalley's Pond

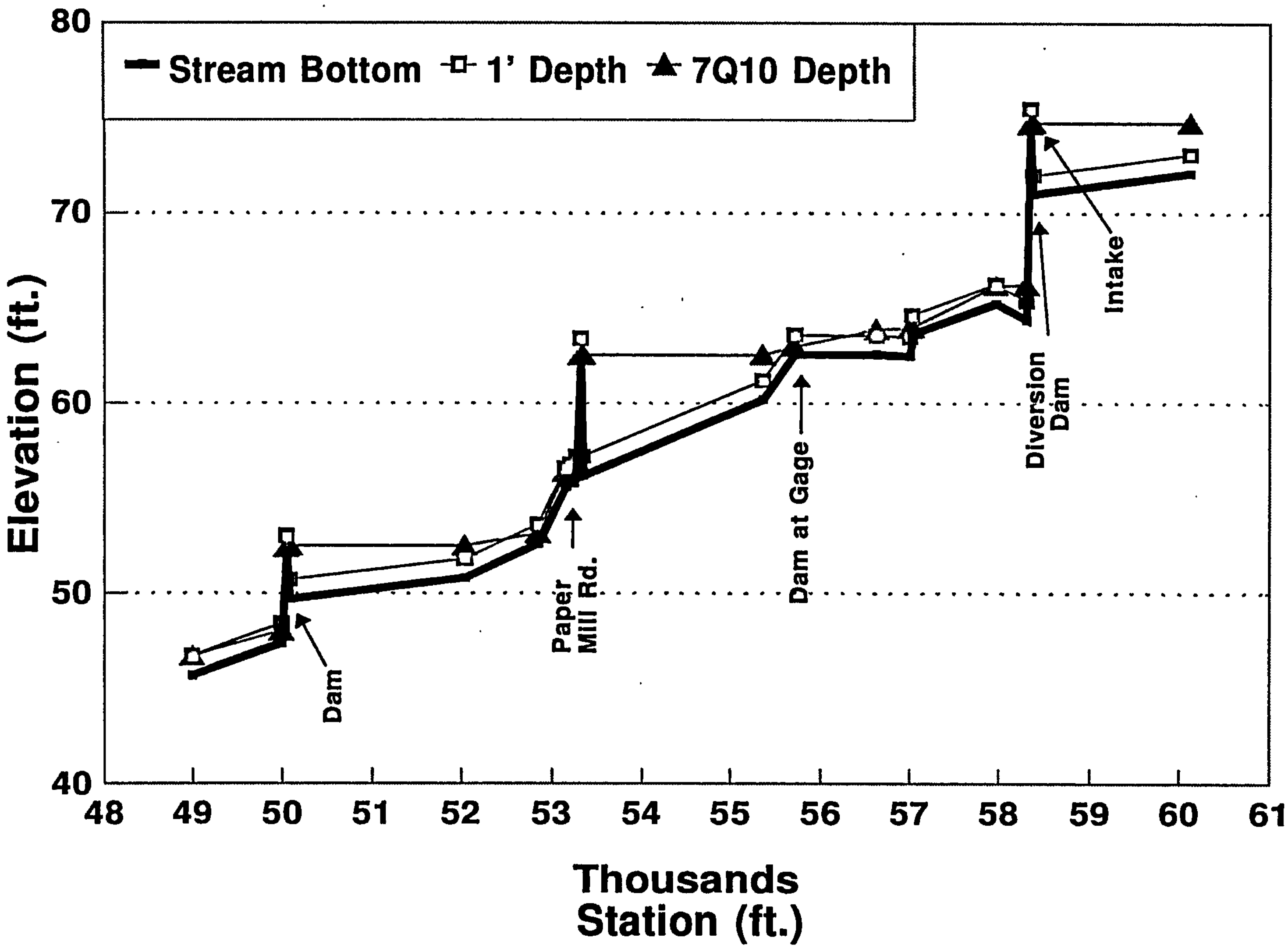
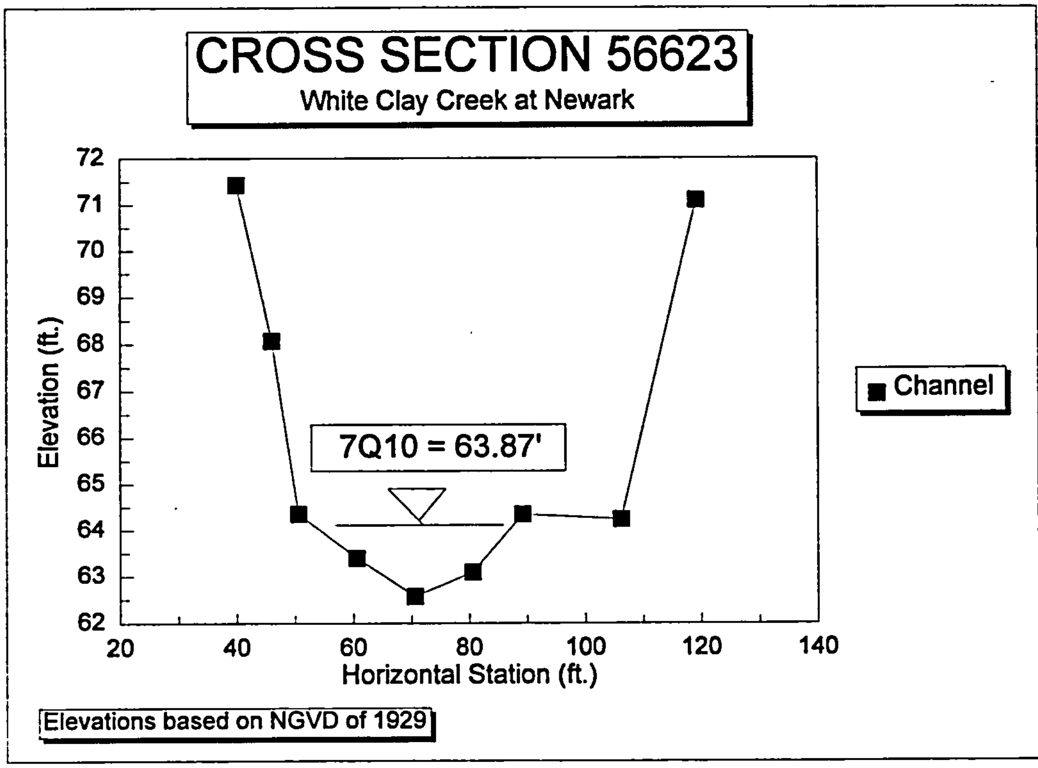


Figure 14. Stream Profile Along White Clay Creek at Newark



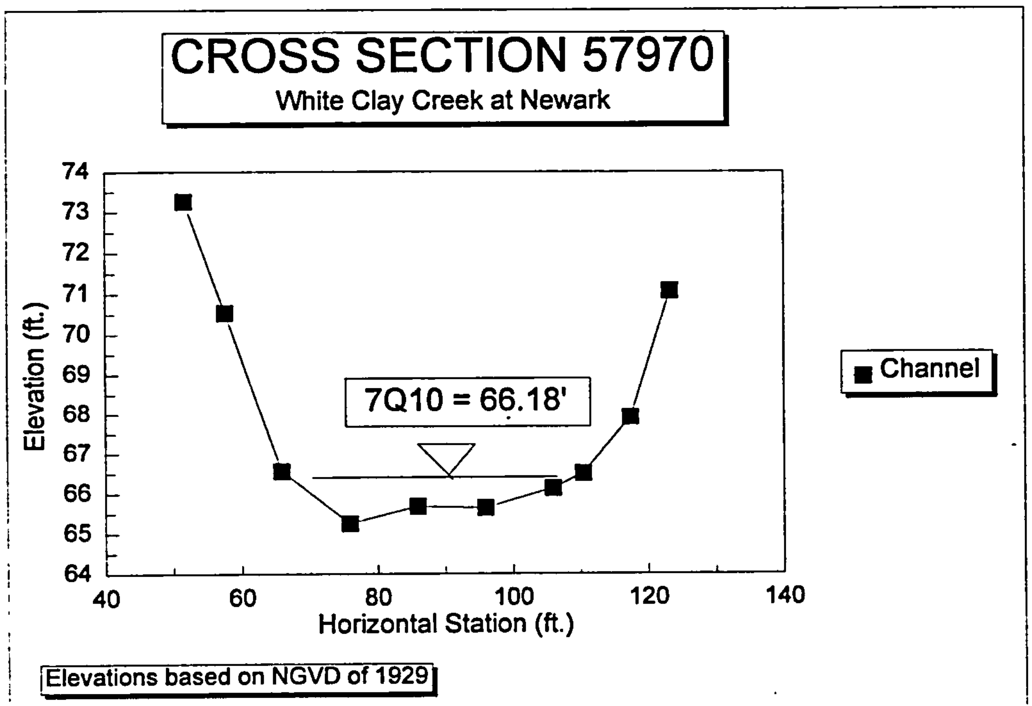


Figure 15. Cross-Sections 56623 and 57970 along White Clay Creek at Newark

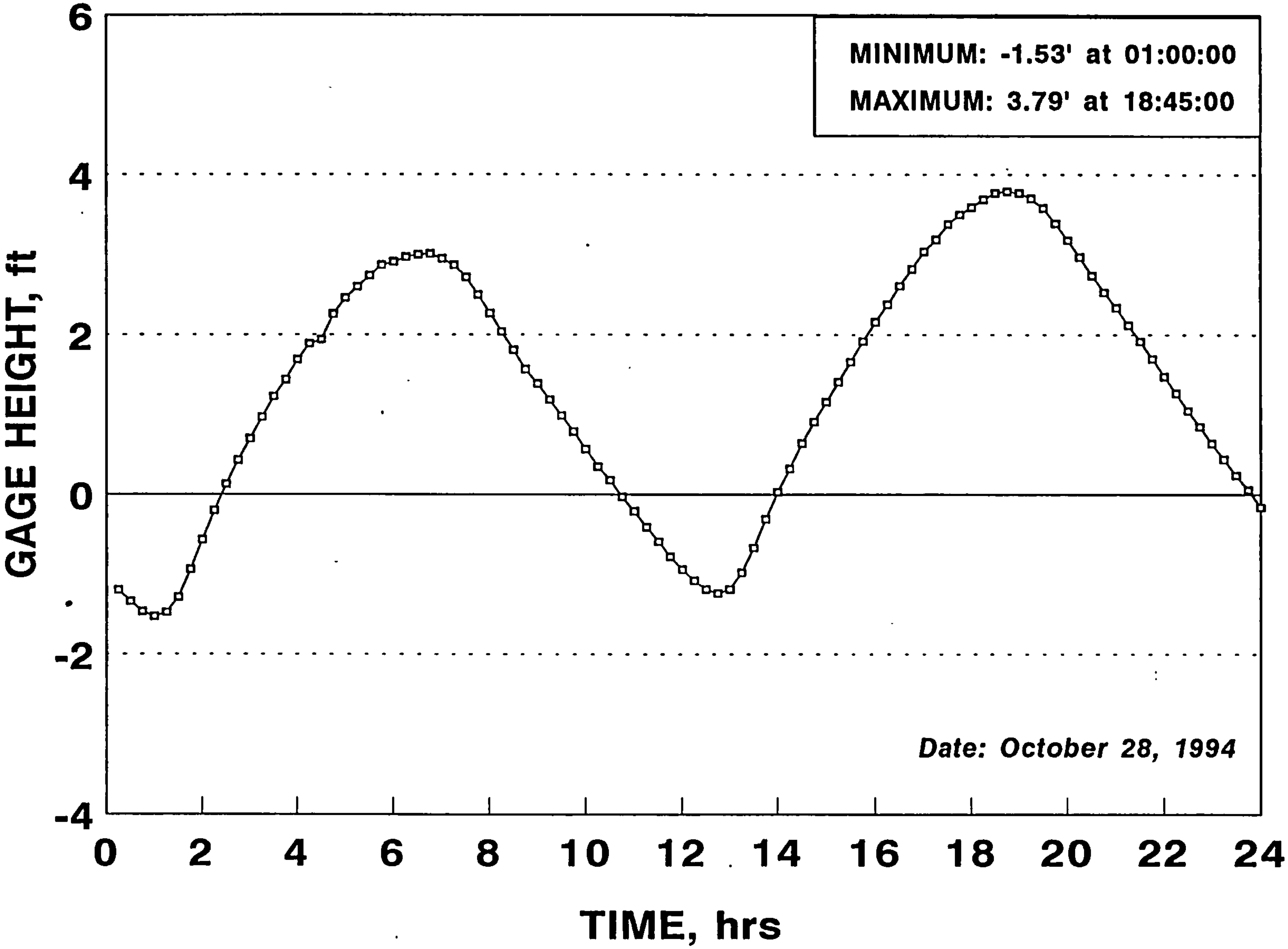


Figure 16. Tidal Cycle for Christina River at Newport

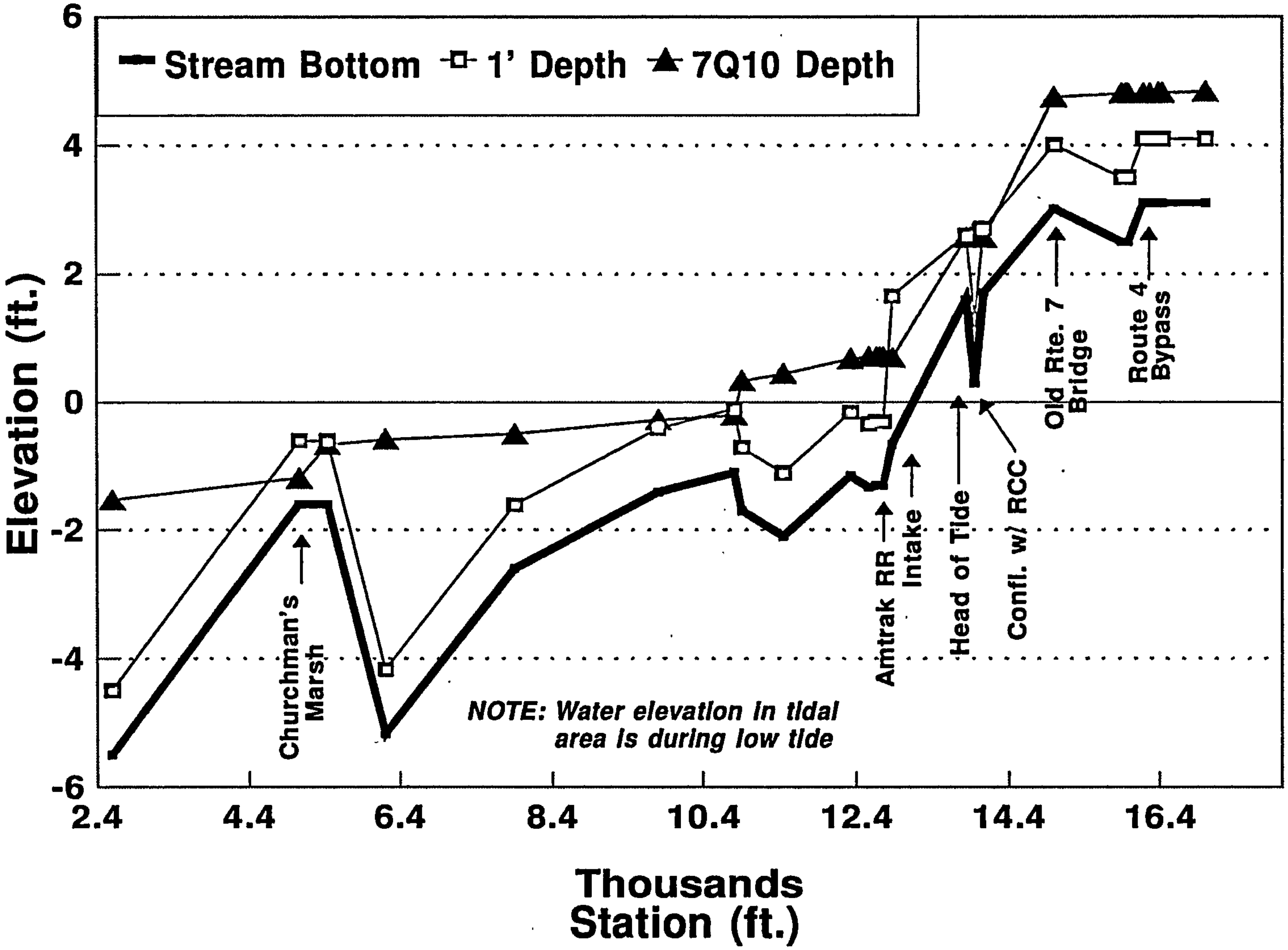
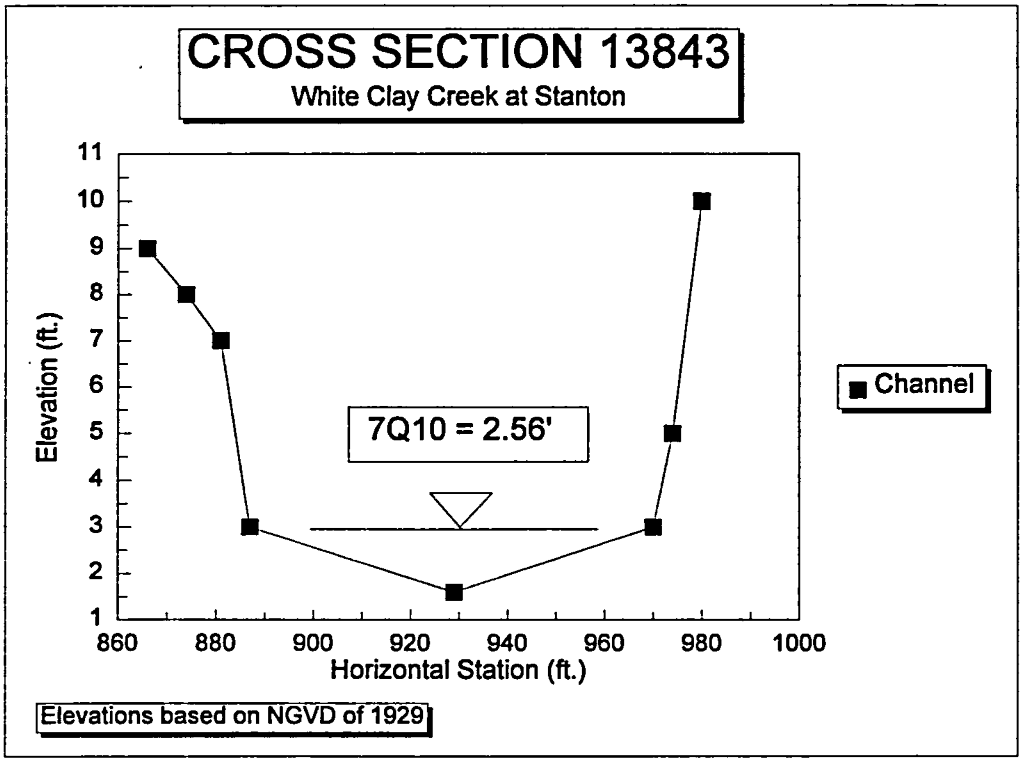


Figure 17. Stream Profile Along White Clay Creek at Stanton



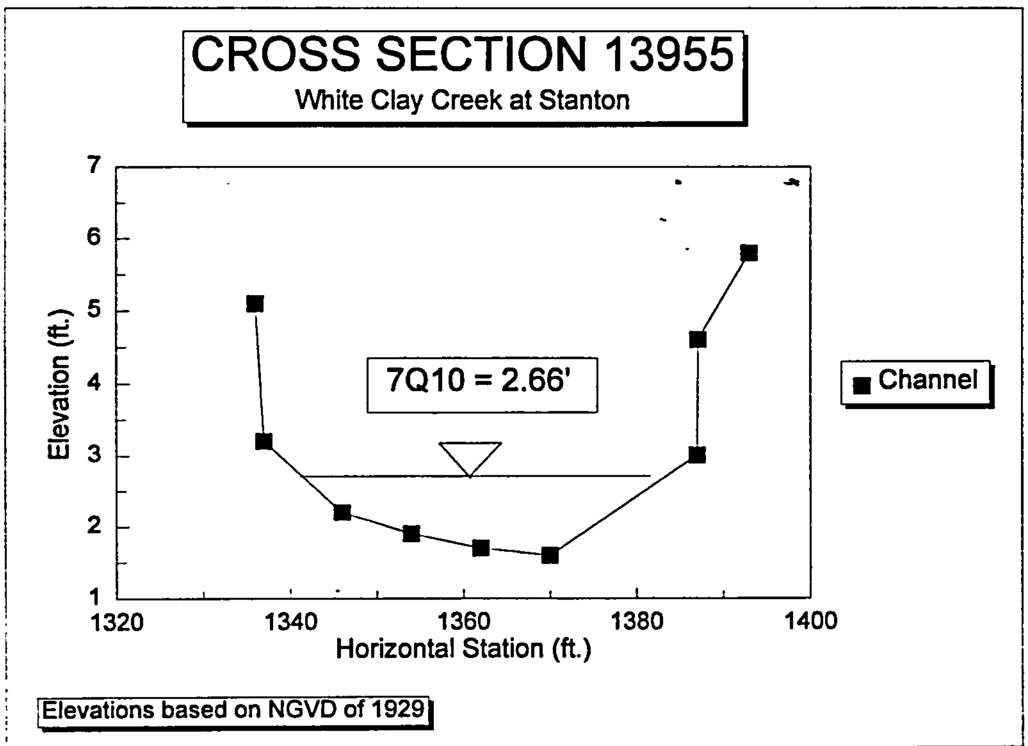


Figure 18. Cross-Sections 13843 and 13955 along White Clay Creek at Stanton

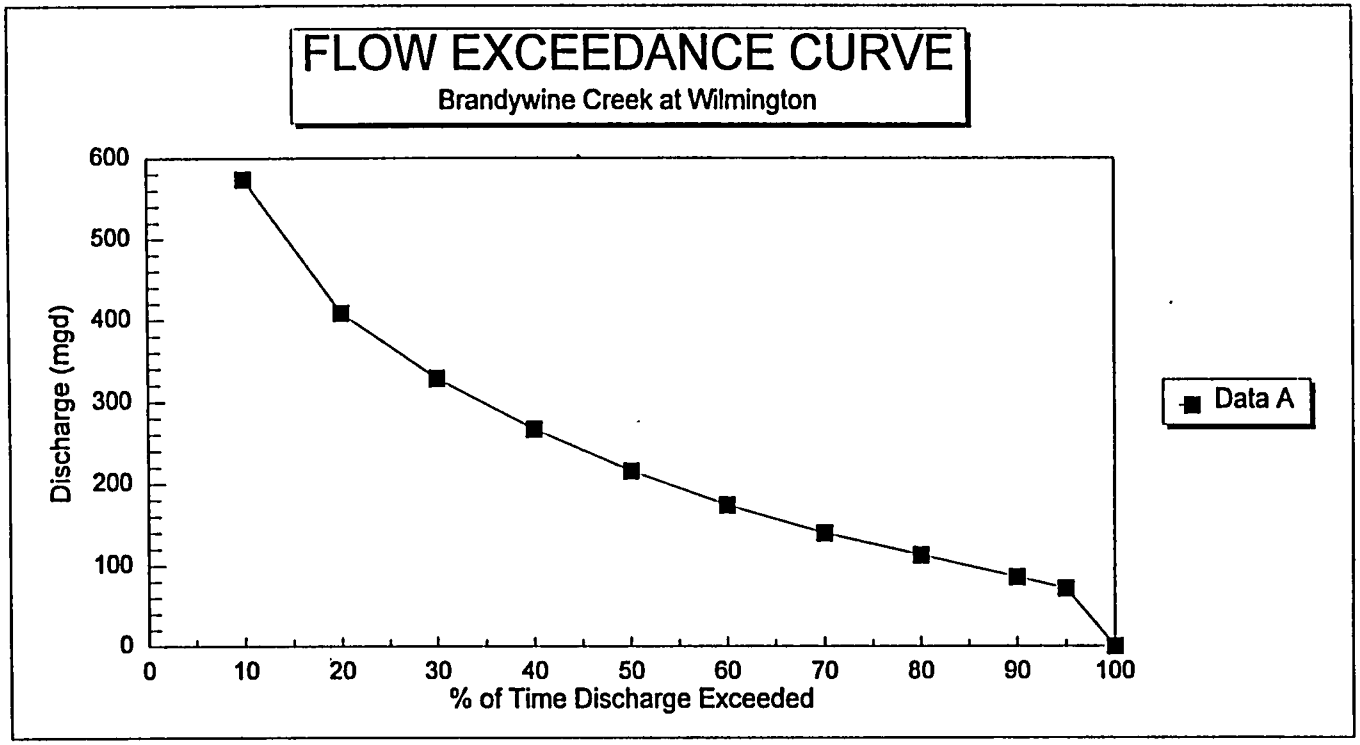


Figure 19. Flow Exceedance Curve for Brandywine Creek at Wilmington

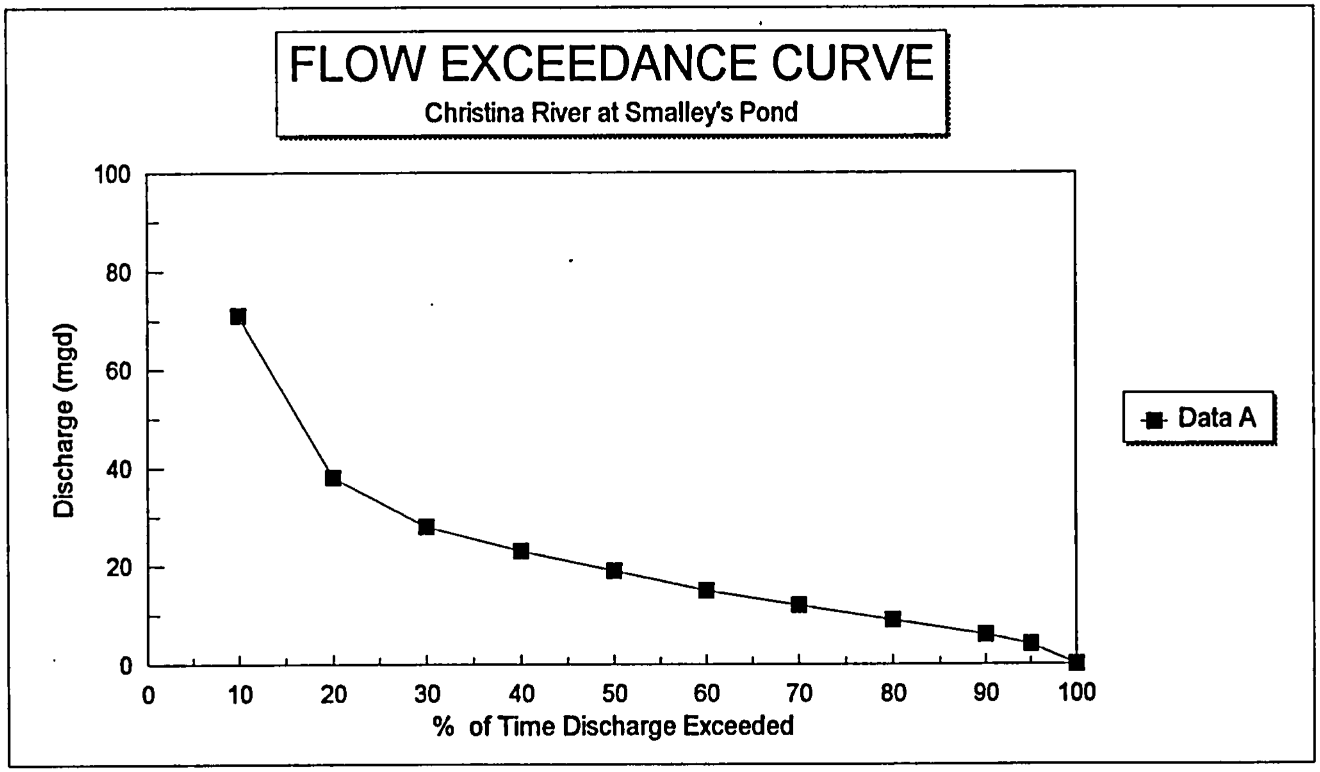


Figure 20. Flow Exceedance Curve for Christina River at Smalley's Pond

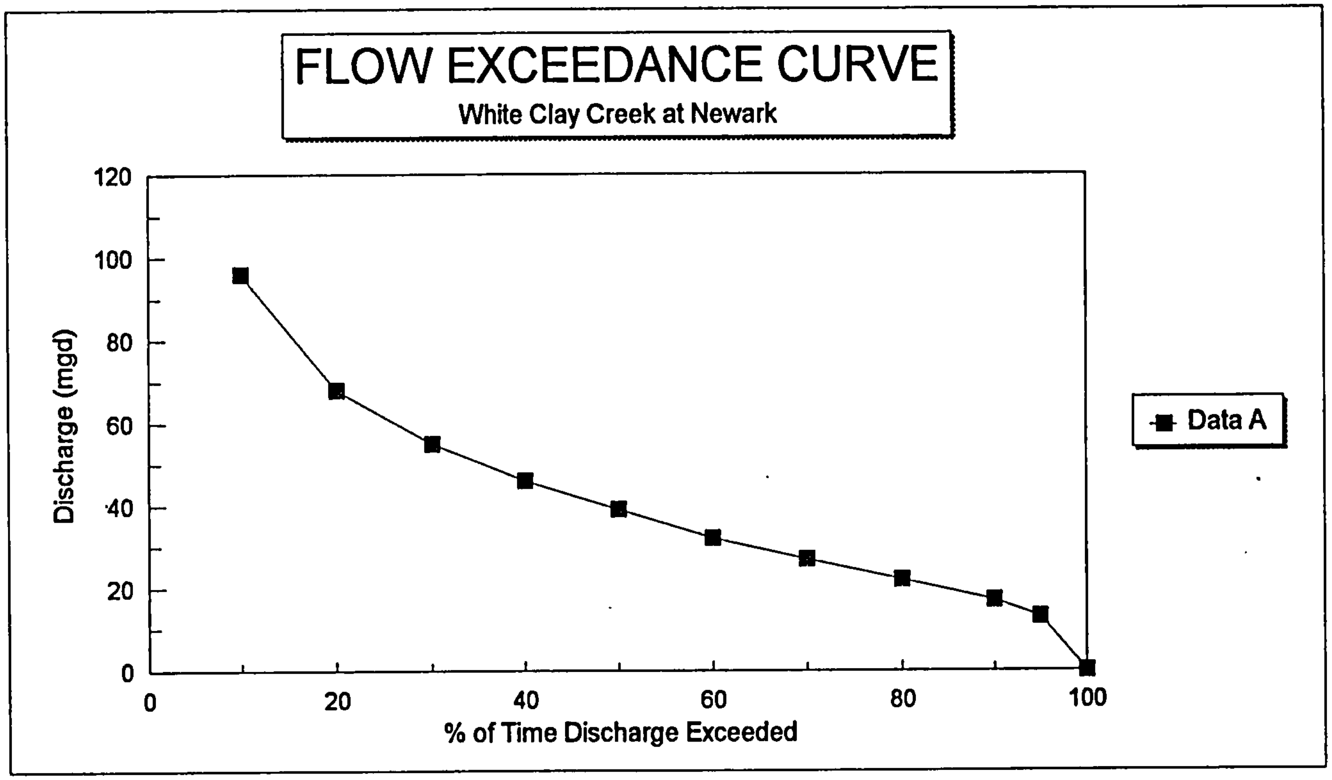


Figure 21. Flow Exceedance Curve for White Clay Creek at Newark

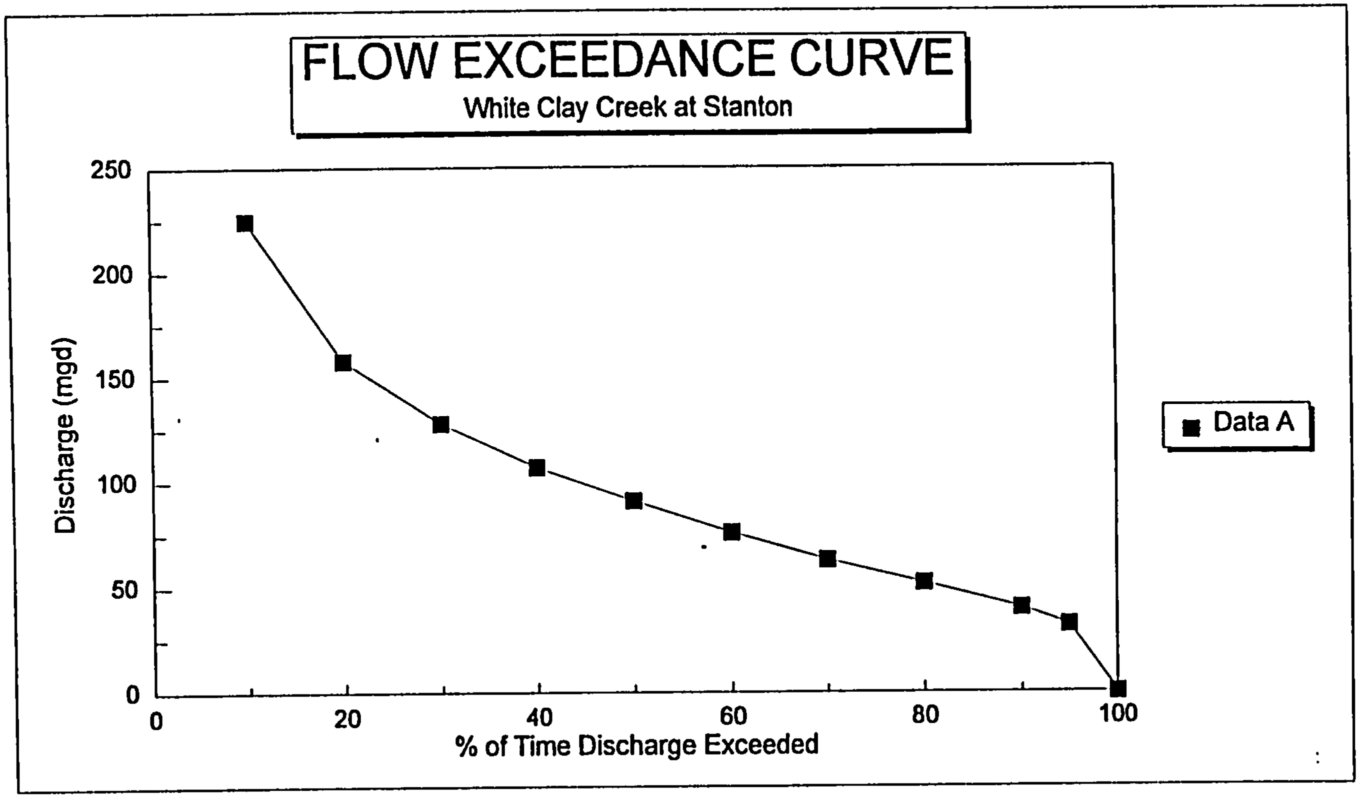


Figure 22. Flow Exceedance Curve for White Clay Creek at Stanton

4. CONCLUSIONS

The formation of the multi-disciplinary Instream Flow Needs Joint Task Force has provided a viable vehicle for the exchange of ideas during the Phase One 7Q10 Assessment. With a broad range of interests and experience applied to the task, an evolutionary process dictated the course of the study.

The utilization of the HEC2 hydraulic model in the assessment represented an innovative step in addressing the issue of passby requirements for public water supply intakes in Northern New Castle County, Delaware. Calibration of the model led to the conclusion that it adequately predicts flow velocity and depth and wetted perimeter for the 7Q10 discharge. Gerald J. Kauffman, water resources engineer with the Water Resources Agency for New Castle County and Richard E. Greene, environmental engineer, Delaware Department of Natural Resources and Environmental Control, who conducted the model runs for the Phase One Assessment also concluded the HEC2 model provides a satisfactory hydraulic model for future wetted perimeter analysis.

Results from the HEC-2 model runs for the four study reaches indicate the 7Q10 flow on the Brandywine at Wilmington exceeds a depth of one foot along 87% of the study reach. For the Christina River at Smalley's Pond, the 7Q10 flow exceeds a depth of one foot along 98% of that study reach. On the White Clay at Stanton, the 7Q10 flow exceeds a depth of one foot along 90% for the reach and 75% of the study reach on the White Clay at Newark. The analysis was conducted for the full tidal cycle. Conclusions are presented for the critical flow condition which is low tide.

Based on data published in <u>Designing and Negotiating Studies Using IFIM</u> by the U.S. Fish and Wildlife Service, this depth of one foot and the velocities recorded in the model runs meet the minimum criteria recommended by Bovee, 1975 for most of the target species identified for this study. It was determined by the Joint Task Force that the literature provided by Bovee may not be sufficient for the 7Q10 Assessment. A more intensive fish species evaluation, fish habitat literature search and field assessment should be conducted as part of the next phase of study. The model runs also disclosed the 7Q10 depths are less than one foot along the riffle sections just downstream from the dam between Market Street and Baynard Boulevard and downstream from City Dam on the Brandywine at Wilmington. A similar situation occurs in the riffle sections just downstream from the small dam within the study reach on the White Clay at Newark.

During the course of the study, research continued to develop more data relating to the selected target fish species and the minimum criteria for survivability. Contact was made with other jurisdictions such as North and

South Carolina and the state of Georgia where instream flow needs studies had been previously conducted in an attempt to fill the data gaps involving certain species. Roy W. Miller, program manager of the Fisheries Section, Division of Fish and Wildlife, DNREC, was active in this effort on behalf of the Joint Task Force and expressed concern that habitat information was lacking in the study reaches. Further work was needed to determine which species are dependent on stream flow conditions at the four study reaches. He advised the Study Coordinating Group that additional fish habitat information would be required before the Division of Fish and Wildlife would feel comfortable making a recommendation to a utility to regulate withdrawals during periods of low stream flow.

Miller also informed the Study Coordinating Committee of a suggestion from the U.S. Fish and Wildlife Service that a wetted perimeter analysis may be the next logical step for the 7Q10 assessment by integrating habitat data in the HEC2 model. Field investigation would be required to quantify the habitat and species present within the study reaches in order to further refine the activities conducted in the Phase One assessment.

The Study Coordinating Group concluded the additional study was needed before the 7Q10 assessment was considered complete. A proposal incorporating the needed data elements was developed and approved by the Joint Task Force on April 13, 1995. Until the results of the Phase Two study effort are known, recommendations regarding a statewide policy for passby requirements during periods of low stream flow can not be developed.

5. RECOMMENDATIONS

The target fish species identified in the Scope of Work were based on the best available data at the time the 7Q10 assessment began. The Fish and Wildlife Division, Delaware Department of Natural Resources and Environmental Control has indicated some reservation about the development of a statewide policy regarding instream flow needs based on this general approach. It has been recommended by the Joint Task Force that additional information such as habitat suitability and water quality data within the study reaches be generated through more detailed study (Phase Two) before the 7Q10 assessment can be considered complete. Recognizing specific concerns advanced by the DNREC Watershed Assessment Section, the Phase Two Study should address all stream flow needs including water quality. The Joint Task Force, recognizing the need to resolve this issue, further recommended that additional funding be provided to conduct this additional activity.

Development of Phase Two of the 7Q10 Assessment will also provide needed data to develop a wetted perimeter analysis using the habitat information obtained in this second phase effort and provide a more appropriate means for evaluating the effect of a 7Q10 passby requirement on public water purveyors withdrawing from the streams in the study areas while seeking to protect all instream flow needs.

PHASE TWO STUDY OUTLINE

A. Revisit target fish species cited in Phase One Scope of Work and make revisions as necessary and conduct fish abundance investigations in the four study reaches.

B. Revisit target fish species habitat criteria through literature search to:

1. Determine habitat criteria to include depth, velocity, substrate type and temperature for various life stages.

2. Describe the effects of varying instream flows using a wetted perimeter analysis and relate this analysis to habitat types in the study reaches.

3. Determine these criteria for critical low flow period (June-November).

C. Conduct field reconnaissance to identify habitat types in Phase One study reaches.

D. Conduct a water quality analysis to evaluate the adequacy of the 7Q10 as a minimum flow standard in accordance with the State of Delaware Surface Water Quality Standards. Prepare temperature/discharge data for public water supply intakes in study reaches and dissolved oxygen and chloride in tidal portion.

E. Conduct wetted perimeter breakpoint slope analysis using habitat data generated in Phase Two, incorporating depth, flow and velocity data generated in Phase One of the 7Q10 assessment. The analysis will account for seasonal variations in flow for the full tidal cycle including low, slack, and high tide conditions.

F. Prepare automated mapping, refining GIS products produced for Phase One.

G. Evaluate the effect of 7Q10 passby requirement on public water supply intakes within the study reaches and the protection of all instream flow needs, including a review of Delaware River Basin Commission and DNREC dockets which apply within the study reaches.

H. Prepare report to the Department of Natural Resources and Environmental Control regarding the suitability of a 7Q10 passby requirement for public water supply and other withdrawals as a statewide regulatory policy.

6. REFERENCES

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6. Guire, Erin. Habitat Requirements of the Red Breast Sunfish, May 1995.

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16. Wilmington Suburban Water Corporation. Water Surface Profiles (HEC-2) for the White Clay Creek near Stanton, 1994.

APPENDIX A

HEC-2 Model Input/Output

Brandywine Creek at Wilmington

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T1 BRANDYWINE CREEK AT WILMINGTON
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 49.3 MGD = 76.3 CFS
J1    -10       7                                                     -1.53
J2     -1
J3     38      43      42       1       8      26       4
NC   .070    .070    .040      .1      .3
QT      9    30.0    46.1    58.5   60.30   67.25   76.28    92.2   184.4  139.78

X1    204      15     385     555       0       0       0       0       0       0
GR      4       0     3.3     385     0.2     409    -4.3     428    -4.9     435
GR   -5.3     445    -5.6     455      -6     475    -4.8     485    -5.6     505
GR   -4.7     525    -5.3     535    -4.6     545      16     555    14.3     560
X1    238      10     940    1105    1670    1670    1670       0       0       0
GR    4.4       0     3.1     940     2.4     955     1.1     980    -0.4    1000
GR      2    1100     6.1    1105     9.4    1115    12.6    1145      25    1146
X1    239      11     900    1100      50      50      50       0       0       0
GR     25       0      15     840     7.3     900     4.6     940     9.5     941
GR    8.7     987     4.6     988     4.6    1100     5.8    1120    12.6    1132
GR     25    1133       0       0       0       0       0       0       0       0
X1    240      10     900    1110      50      50      50       0       0       0
GR     25       0    10.4     870     7.6     900     5.6     920     3.6     960
GR    1.5     980     2.6    1100       8    1110    12.6    1127      25    1130
X1    255      19    78.4   189.4     792     792     792
GR  21.16       0   17.51      20   17.14      40   14.22    56.4   11.02    78.4
GR  10.24    89.4    9.94    99.4    8.89   109.4    8.04   119.4    7.54   129.4
GR   8.14   139.4    7.34   149.4    9.14   159.4    8.84   169.4    9.34   179.4
GR  11.13   189.4   14.42   202.7   16.81   215.1   22.30   228.8
X1    265      15     520     773     528     528     528       0       0       0
GR   17.8       0   14.32     520   13.41     540   13.61     560   13.41     580
GR   12.6     600   13.71     620   13.51     640   13.11     660   15.38     680
GR   20.5     700   22.41     720   24.15     740   24.43     760   24.69     773
X1    267      27      40   234.1     106     106     106
GR  22.25       0   20.36      20   19.32      40   17.32    49.1   13.38    60.7
GR  12.11    64.1   11.82    74.1   11.86    84.1   12.19    94.1   11.82   104.1
GR  11.02   114.1   11.57   124.1   11.52   134.1   11.65   144.1   12.09   154.1
GR  12.19   164.1   11.77   174.1   12.00   184.1   12.79   194.1   12.44   204.1
GR  12.69   214.1   12.02   224.1   13.05   234.1   15.26   239.8   16.75   248.8
GR  20.45   257.8   22.96   277.8
X1    293      21    23.2   154.7    1373    1373    1373
GR  23.84       0   19.98     3.5   15.00    23.2   14.56    24.7   13.98    34.7
GR  13.34    44.7   12.79    54.7    12.5    64.7   12.63    74.7   12.17    84.7
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GR 12.29    94.7   11.71   104.7   12.17   114.7   12.34   124.7   12.69   134.7
GR 13.67   144.7   15.00   154.7   16.97   167.0   19.45   200.2   20.49   220.2
GR 22.25   240.2
X1   294      15     157     292      53      53      53       0       0       0
GR  26.4       0      18     143    25.5     144    25.5     157    17.3     158
GR  17.5     170      16     180    16.7     190    13.2     250    13.3     260
GR  15.8     270    16.3     280    17.5     286    20.5     292      25     293
X1   295      16     162     302      50      50      50       0       0       0
GR  57.8       0    36.9      45    34.9      60    35.5      79    28.9      81
GR  25.6     145    29.3     146    29.3     162    23.3     163    23.3     290
GR  24.2     298    29.3     302    31.4     328    31.5     359    38.7     398
GR  84.2     500       0       0       0       0       0       0       0       0
X1   296      26     156     350      50      50      50       0       0       0

GR  57.8       0    49.3      16    41.1      31      34      58    32.9     105
GR  28.6     128    28.2     150    27.9     156      23     160    20.6     170
GR  20.2     180    21.1     190    21.1     210    18.3     230    19.3     250
GR  19.6     270      20     280    19.5     290    20.2     300      19     330
GR  20.6     340      23     342      28     350    29.6     400    34.5     430
GR  84.2     500       0       0       0       0       0       0       0       0
X1   299      22    37.3   158.3     264     264     264
GR 24.48       0   19.57    18.0   16.88    29.0   15.86    37.3   15.38    38.3
GR 14.76    48.3   15.13    58.3   15.38    68.3   15.05    78.3   15.01    88.3
GR 14.88    98.3   14.67   108.3   13.96   118.3   14.80   128.3   14.63   138.3
GR 14.38   148.3   15.71   158.3   18.40   164.1   19.99   171.7   23.60   180.3
GR 25.52   200.3   26.29   220.3
X1   305       4     1.0   202.0     500     500     500       0       0       0
GR    30       0    23.5     1.0    23.5   201.0      30   202.0       0       0

X1   332      27     190     315     595     595     595       0       0       0
GR    83       0    66.1      40    65.8      57    64.7      64      61     103
GR  56.6     114    40.5     137    32.5     138    34.2     172    35.5     181
GR  36.9     182    35.1     190      27     198    26.2     202      26     211
GR  25.3     222    25.1     241    25.4     253    24.7     261    26.5     272
GR  25.1     281    26.1     291    27.1     310    28.4     315    38.3     392
GR    49     407    62.6     462       0       0       0       0       0       0

X1   341      21     161     302     450     450     450       0       0       0
GR    85       0    55.8      70    47.1     100    46.8     108    38.3     109
GR  31.1     148    41.3     149    41.3     161    34.8     162    28.9     178
GR  27.9     190    27.6     210    27.1     220    24.1     230    24.3     285
GR  25.1     295    28.1     302    31.8     320    36.3     321    50.6     400
```

GR	62.5	420	0	0	0	0	0	0	0	0
X1	342	19	173	350	50	50	50	0	0	0
GR	85	0	55.8	70	47.1	100	46.8	108	38.3	109
GR	33.7	148	46.7	149	46.7	173	34.3	174	34.9	192
GR	34.3	217	34.1	240	33.6	250	33.5	260	33.5	330
GR	34.1	345	37.2	350	47.9	351	62.5	375	0	0
X1	343	24	110	350	50	50	50	0	0	0
GR	85	0	55.8	70	44	80	37.9	100	36.6	101
GR	32.7	110	30.3	119	29.5	160	29.9	170	29.1	200
GR	28.3	210	26	230	28.7	250	30.4	260	31.4	280
GR	31.4	290	30.3	310	30.9	320	30.8	330	34	338
GR	37.8	350	38.5	358	40.8	364	62.5	375	0	0
X1	368	22	144	342	1320	1320	1320	0	0	0
GR	75	0	39.2	120	50.5	121	49.9	135	46.3	144
GR	42.8	176	43.6	178	41.5	180	42.2	190	41.4	200
GR	40.6	210	40.5	220	39.1	230	39.6	240	39.5	250
GR	41.1	290	41.3	300	42.2	310	42.5	320	42.7	333
GR	49.6	342	81	550	0	0	0	0	0	0
X1	369	18	143	342	50	50	50	0	0	0
GR	75.3	0	50.1	143	48.7	150	46.1	174	49.4	180
GR	49.3	200	48.4	220	48.7	230	47.4	240	48	250
GR	46.7	260	48.2	270	48.7	280	48.9	300	49	320
GR	49.5	330	49.6	342	81	550	0	0	0	0

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ER

PAGE 1

THIS RUN EXECUTED 06-06-95

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**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED MAY  1984
  ERROR CORR -  01,02,03,04,05,06
  MODIFICATION -  50,51,52,53,54,55,56
  IBM-PC-XT VERSION AUGUST 1985
**************************************************
```

T1 BRANDYWINE CREEK AT WILMINGTON
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 49.3 MGD = 76.3 CFS

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	-10.	7.	0.	0.	.000000	.00	.0	0.	-1.530	.000

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

J3 VARIABLE CODES FOR SUMMARY PRINTOUT

38.000	43.000	42.000	1.000	8.000	26.000	4.000	.000	.000	.000

ELEVATION -10. 0. 10. 20. 30. 40. 50. 60. 70. 8
0.

SECNO CUMDIS

06-06-95 16:05:50
PAGE 6

THIS RUN EXECUTED 06
-06-95

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**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED MAY  1984
  ERROR CORR -  01,02,03,04,05,06
  MODIFICATION -  50,51,52,53,54,55,56
  IBM-PC-XT VERSION AUGUST 1985
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NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

THE 7Q10 = 49.3 MGD = 7

SUMMARY PRINTOUT

	SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
	204.000	76.28	-6.00	-1.53	4.47	.17	130.19
*	238.000	76.28	-.40	.46	.86	3.77	47.18
*	239.000	76.28	4.60	4.84	.24	2.77	119.69
	240.000	76.28	1.50	4.97	3.47	.18	171.81
*	255.000	76.28	7.34	8.32	.98	3.99	38.77
	265.000	76.28	12.60	13.77	1.17	1.41	133.78
	267.000	76.28	11.02	13.81	2.79	.24	176.62
	293.000	76.28	11.71	13.87	2.16	.54	109.78
*	294.000	76.28	13.20	14.12	.92	4.42	29.03
*	295.000	76.28	23.30	23.52	.22	2.67	129.02
	296.000	76.28	18.30	23.65	5.35	.11	183.56
	299.000	76.28	13.96	23.65	9.69	.07	177.71
*	305.000	76.28	23.50	23.66	.16	2.31	200.05
	332.000	76.28	24.70	26.22	1.52	1.17	87.99

	341.000	76.28	24.10	26.34	2.24	.53	75.38
*	342.000	76.28	33.50	33.80	.30	3.00	92.58
	343.000	76.28	26.00	33.96	7.96	.08	230.80

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06-06-95 16:05:50
PAGE 7

	SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
*	368.000	76.28	39.10	40.04	.94	3.97	43.17
*	369.000	76.28	46.10	47.58	1.48	4.22	33.41

1
06-06-95 16:05:50
PAGE 8

SUMMARY OF ERRORS AND SPECIAL NOTES

CAUTION SECNO= 238.000 PROFILE= 1 CRITICAL DEPTH ASSUMED
CAUTION SECNO= 238.000 PROFILE= 1 PROBABLE MINIMUM SPECIFIC ENERGY

APPENDIX B

HEC-2 Model Input/Output

Christina River at Smalley's Pond

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T1 CHRISTINA RIVER AT SMALLEYS POND
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 2.1 MGD = 3.23 CFS
J1     -10       5                                                      -1.53
J2      -1
J3      38      43      42       1       8      26       4
NC    .090    .090    .035      .1      .3
QT       9    1.10    1.63    2.36    3.23    6.50    12.5    12.8    25.7   14.62

X1   55764      39   324.6  1075.3       0       0       0       0    -2.1       0
GR      36       0      30    41.6      30    76.7    29.9   141.1      30   216.8
GR    29.5   253.6    23.7   324.6    19.5   384.1      16   445.3    10.9   502.5
GR     7.6   510.2     5.2   532.7     4.1   598.6     2.0   630.7     0.1   630.8
GR     0.1     677     2.8   678.1     6.7   729.4     4.9   773.4     4.5   845.5
GR       4   931.8       4   995.3      14    1016    21.4  1075.3      24  1124.8
GR    26.1  1186.9    27.5  1245.8    27.8  1303.7    27.2  1343.6      26  1371.4
GR    26.3    1411    27.3  1485.8    27.8  1548.9    28.9  1621.7    29.5  1671.8
GR    33.4  1729.2    35.1  1794.9    35.9  1868.9      36  1930.3       0       0
ET       0       0    10.4     8.4     6.4     7.1     405    1010       0       0
NC       0       0       0     0.1     0.3       0       0       0       0       0
X1   56750       0       0       0     996     986     986       0     2.1       0
ET       0       0    10.4     8.4     6.4     7.1     357    1121       0       0
X1   58500      62   407.1    1071    1750    1750    1750       0       0       0
GR      40       0    38.8    53.1    35.7      98    31.3   142.8    28.4     204
GR    25.9   238.5    26.5   249.1    26.5   270.8    24.2   323.7    18.1   363.5
GR    11.3   407.1     8.9   440.2     5.1   466.4     4.1   506.8     3.2   514.9
GR     3.2   530.6     4.9   553.6     4.6   600.8     3.3   618.6     4.6   654.8
GR     4.7   704.1     3.2   753.4     4.6   821.2       3     835       1   836.5
GR       1   860.4       3   861.4     5.5   911.6     3.5  1005.1     0.5  1006.1
GR     0.5  1042.8     3.5    1070     7.7    1071    20.9  1165.8    21.3  1242.2
GR    21.1  1311.5    22.6  1372.9    24.1    1429    23.6  1463.7      22  1495.6
GR    20.9  1547.2    20.9  1605.7    23.8  1646.9    28.9  1672.7    26.5  1690.3
GR    29.2  1750.9    31.9    1813    31.9  1845.5      29  1916.7    29.1  1997.1
GR    29.3  2056.2    36.2  2101.3    32.3  2113.2    32.3  2705.1    32.7  2743.3
GR    37.1  2760.1    38.1  2831.5    37.1  2919.1    38.6  3040.7    39.6  3109.4
GR      39  3139.6      40  3179.1       0       0       0       0       0       0
ET       0       0    10.4     8.4     6.4     7.1     357    1121       0       0

X1   58915       0       0       0     415     415     415       0     0.1       0
ET       0       0    10.4     8.4     6.4     7.1     675    1900       0       0

NC       0       0       0     0.3     0.5       0       0       0       0       0
```

X1	58965	28	874.5	921	50	50	50	0	0	0
X3	10	0	0	0	0	0	0	6.3	6.3	0
GR	35.3	0	33.8	100	31.3	200	27.8	300	25.8	400
GR	23.8	500	20.8	600	14.8	700	12.3	800	8.8	874.5
GR	1.6	875.5	0.6	894.5	1.2	904.5	1.3	909	5.8	920
GR	9.3	921	6.3	1021	6.8	1121	6.8	1221	7.3	1321
GR	7.8	1421	8.3	1521	9.1	1621	10.6	1721	12.6	1821
GR	16.1	1921	21.1	2021	25.1	2121	0	0	0	0
ET	0	0	10.41	8.41	6.41	7.11	675	1900	0	0
SB	1.05	1.56	2.6	0	46.5	0	309	0	0.6	0.6
X1	58982	0	0	0	17	17	17	0	0	0
X2	0	0	1	7.6	6.3	0	0	0	0	0
X3	10	0	0	0	0	0	0	6.3	6.3	0
BT	28	0	35.3	35.3	100	33.8	33.8	200	31.3	31.3
BT	300	27.8	27.8	400	25.8	25.8	500	23.8	23.8	600
BT	20.8	20.8	700	14.8	14.8	800	12.3	12.3	874.5	8.8
BT	8.8	875.5	12	7.6	894.5	11.7	7.3	904.5	11.4	7
BT	909	11.3	7.2	920	11.2	6.7	921	9.3	9.3	1021
BT	6.3	6.3	1121	6.8	6.8	1221	6.8	6.8	1321	7.3
BT	7.3	1421	7.8	7.8	1521	8.3	8.3	1621	9.1	9.1
BT	1721	10.6	10.6	1821	12.6	12.6	1921	16.1	16.1	2021
BT	21.1	21.1	2121	25.1	25.1	0	0	0	0	0
ET	0	0	10.4	8.4	6.4	7.1	675	1930	0	0
X1	59032	0	0	0	50	50	50	0	0	0
NC	0	0	0	0.1	0.3	0	0	0	0	0
ET	0	0	10.4	8.4	6.4	7.1	875	1845	0	0
X1	59207	13	41.6	96.7	175	175	175			
GR	7.2	0	7.31	20	4.8	40	3.97	41.6	2.83	48.2
GR	1.47	58.2	1.34	68.2	0.34	78.2	-0.2	88.2	2.9	95.7
GR	6.59	96.7	6.27	116.7	7.96	136.7				
X1	59926	15	40	95.2	719	719	719			
GR	9.99	0	6.92	20	5.21	40	3.16	40.5	1.21	50.5
GR	0.46	60.5	0.96	70.5	2.29	80.5	2.54	90.5	3.42	94.5
GR	4.10	95.2	5.15	104.9	6.70	112.6	7.52	132.6	7.80	152.6
X1	60440	45	1290	1531	514	514	514	0	0	0

GR	24	637	24	638	24	639	24	640	20	700
GR	16.7	880	16.7	881	16.4	950	15.8	1050	15.4	1130
GR	16	1230	15.9	1290	6.6	1291	5.8	1295	4	1298
GR	1.6	1310	1.4	1320	0.3	1330	0.2	1345	-1.2	1360
GR	-1.2	1370	-1	1380	-0.5	1410	-0.4	1430	1.6	1460
GR	4	1475	7.3	1480	8.9	1530	15.5	1531	16	1550
GR	16.3	1605	16.5	1645	16.6	1705	16.4	1755	15.6	1795
GR	16.6	1845	22.1	1910	23.6	1950	28.6	1970	29.1	2010
GR	32.7	2050	32.7	2090	32.2	2130	34.2	2230	39.2	2280
ET	0	0	10.4	8.4	6.4	7.1	917	1706	0	0
NC	0	0	0	0.3	0.5	0	0	0	0	0
X1	60530	38	1293	1494	90	90	90	0	0	0
GR	24	637	24	638	24	639	24	640	20	700
GR	16.7	880	16.7	881	16.4	950	15.8	1050	15.4	1130
GR	16	1230	15.9	1290	15.8	1293	9.8	1294	9.8	1340
GR	9.8	1390	9.8	1440	9.8	1493	16	1494	16	1496
GR	14.2	1497	15.5	1510	16	1540	16.3	1560	16.5	1590
GR	16.6	1605	16.4	1610	15.6	1660	16.6	1710	22.1	1775
GR	23.6	1815	28.6	1835	29.1	1875	32.7	1915	32.7	1955
GR	32.2	1995	34.2	2095	39.2	2145	0	0	0	0
ET	0	0	10.4	8.4	6.4	7.1	350	1250	0	0
X1	60805	35	400	1110	275	275	275	0	0	0
GR	41.3	0	38.3	100	32.3	200	26.8	300	19.8	400
GR	11.5	527	10.1	530	6.9	560	6.6	590	6.4	630
GR	7.8	680	7.8	710	7.7	750	7.6	790	7.5	810
GR	7.4	860	7.1	880	7.2	910	7.6	990	10.1	1020
GR	11.4	1025	14.1	1050	16.6	1110	16.4	1160	15.6	1200
GR	16.6	1250	22.1	1315	23.6	1355	28.6	1375	29.1	1415
GR	32.7	1455	32.7	1495	32.2	1535	34.2	1635	39.2	1685
ET	0	0	10.4	3.4	6.4	7.1	670	1342	0	0
NC	0	0	0	0.1	0.3	0	0	0	0	0
X1	61700	55	787	1157.1	895	895	895	0	0	0
GR	44	0	43.1	38	40.8	88	40.4	123.5	38	172.6
GR	36.5	236.8	33.7	287.4	30.8	345.6	30.8	380.1	32.5	416.6
GR	33.2	446	31.2	483.6	27.1	519.8	22.5	585.2	22.1	611.4
GR	19.7	650.1	15.5	686.6	14.5	710.9	11.2	738.9	10.9	770.2
GR	11	787	10.4	797	7.7	842.1	3.1	882	2.4	912
GR	6.7	962	8.5	1022.1	8.6	1061.9	8.7	1097	10.4	1152
GR	11.5	1157.1	11.9	1217.7	14.9	1263.6	15.6	1289.8	15.9	1330.4
GR	21.9	1382.3	25.7	1414.2	27.1	1449.7	29.7	1482.3	27.9	1514.9

GR	27.9	1530.7	27.8	1549.8	28.7	1582.7	27.2	1632.3	27.2	1676.1
GR	30	1736.3	31.4	1787.1	35.3	1838.9	36	1886.5	35	1907.4
GR	35	1931.8	37.6	1992.2	36.4	2024.7	40.7	2050.9	44.1	2084.5
ET	0	0	10.4	5.4	6.4	7.1	390	1290	0	0
X1	63850	44	441.9	540	2150	2150	2150	0	0	0
GR	44	0	42.2	31.8	44.4	91.2	40.7	152.4	35.3	217

GR	29.1	267	27.9	298.9	27	343.3	22.1	384.8	20	415.8
GR	12.7	441.9	11.3	467.9	10.5	468.9	4.7	477.9	3.1	493
GR	7.2	508.1	8.5	522.9	10.5	530	12.6	540	11.5	591.2
GR	11	640.5	11.4	699	10.9	777.2	10.5	855.7	10.8	911.8
GR	11.2	988.1	13.3	1035.9	14.5	1084.8	14.3	1127.8	11.5	1167.1
GR	13	1223.2	16.9	1278.5	20.1	1340	25.2	1382.1	26.8	1438.6
GR	27.6	1492	28	1566.8	30.1	1615.7	31.9	1697.5	34.3	1745.8
GR	37.3	1796	39.8	1850.4	42.5	1908	44	1946.9	0	0
ET	0	0	10.4	8.4	6.4	7.1	1400	2100	0	0
X1	66990	40	1494.9	1838.5	3140	3140	3140	0	0	0
GR	44	0	41.8	69.7	39.1	118.6	34.9	134.9	33.3	214
GR	33.1	260.4	33.3	347.8	35.4	402.6	37.8	442.4	36	503.8
GR	38.8	576.3	36.8	619.0	34.9	684.3	33.2	757.9	33.4	825.9
GR	34.5	889.9	30.7	971.1	30.1	1053.8	29.4	1139.7	26.5	1200.9
GR	23.5	1253.2	19.8	1300.6	18.8	1346.1	12.7	1391.3	11.2	1454.3
GR	11.8	1494.9	11	1595.3	10.6	1675.4	6.5	1676.4	6	1705
GR	6.5	1729.5	10.6	1730.5	11.5	1838.5	11	1883.1	11.4	1933.7
GR	11.8	1992.8	12	2054.7	12.1	2104.9	20	2300	24	2400

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THIS RUN EXECUTED 06

06-95

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HEC2 RELEASE DATED NOV 76 UPDATED MAY 1984
ERROR CORR - 01,02,03,04,05,06
MODIFICATION - 50,51,52,53,54,55,56
IBM-PC-XT VERSION AUGUST 1985

****

T1 CHRISTINA RIVER AT SMALLEYS POND
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 2.1 MGD = 3.23 CFS

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	-10.	5.	0.	0.	.000000	.00	.0	0.	-1.530	.000

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

J3 VARIABLE CODES FOR SUMMARY PRINTOUT

38.000	43.000	42.000	1.000	8.000	26.000	4.000	.000	.000	.000

ELEVATION -5. 0. 5. 10. 15. 20. 25. 30. 35. 4
).

SECNO CUMDIS

06-06-95 16:08:23
PAGE 6

THIS RUN EXECUTED 06
-06-95
****
HEC2 RELEASE DATED NOV 76 UPDATED MAY 1984
ERROR CORR - 01,02,03,04,05,06
MODIFICATION - 50,51,52,53,54,55,56
IBM-PC-XT VERSION AUGUST 1985
****

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

THE 7Q10 = 2.1 MGD = 3.

SUMMARY PRINTOUT

	SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
	55764.000	3.23	-2.00	-1.53	.47	.15	46.42
*	56750.000	3.23	.10	2.10	2.00	.03	48.64
	58500.000	3.23	.50	2.10	1.60	.03	77.02
	58915.000	3.23	.60	2.10	1.50	.04	75.96
	58965.000	3.23	.60	2.10	1.50	.09	35.53
	58982.000	3.23	.60	2.10	1.50	.09	35.53
	59032.000	3.23	.60	2.10	1.50	.09	35.53
	59207.000	3.23	-.20	2.10	2.30	.07	40.22
	59926.000	3.23	.46	2.10	1.64	.10	33.19
	60440.000	3.23	-1.20	2.10	3.30	.01	155.69
*	60530.000	3.23	9.80	9.82	.02	.81	199.01
	60805.000	3.23	6.40	9.83	3.43	.00	484.30
	61700.000	3.23	2.40	9.83	7.43	.00	327.20
	63850.000	3.23	3.10	9.83	6.73	.02	57.70

APPENDIX C

HEC-2 Model Input/Output

White Clay Creek at Newark

```
T1 WHITE CLAY CREEK AT NEWARK
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 11.27 CFS = 7.3 MGD
J1   -10      6                                                   46.7
J2    -1      0     -1
J3    38     43     42      1      8     26      4
NC  .090   .090   .035     .1     .3
QT    12    3.6    6.6    8.8    9.0   11.3   13.9   17.6   21.6   26.3
QT  29.4   35.3   38.7
X1 49000     29    155    235   1585   1585   1585
GR    88      0     84     15     80     30     76     45     72     80
GR    68    100     64    120     60    140     56    150   54.1    155
GR  50.9    158   49.2    166   47.8    169   46.8    175     46    188
GR  45.7    198   45.8    210   47.9    214   50.8    218   51.4    225
GR    52    235     56    255   58.4    400     56    555     56    600
GR    60    685     64    775     68    875     72    998
X11050000    31    585    667   1000   1000   1000
GR  84.9      0   78.9    100   74.4    200   72.4    300   67.4    395
GR  60.7    410   57.7    500   59.3    570   58.6    585   50.4    590
GR  48.9    595   47.9    605   47.8    615   49.1    625   49.0    635
GR  47.4    645   48.9    655   50.4    660   59.1    667   58.8    685
GR  61.4    720   64.1    755   64.6    775   69.1    800   71.1    900
GR  72.6   1000   75.6   1100   77.6   1200   79.1   1300   84.6   1365
GR  90.1   1465
NC     0      0      0     .3     .5
X11050055    27    620    730     55     55     55
GR  84.9      0   78.9    100   74.4    200   72.4    300   67.4    395
GR  60.7    410   57.7    500   57.7    570   57.5    620   52.0    627
GR  52.4    660   52.4    690   52.6    710   55.8    720   59.1    730
GR  59.0    750   61.4    785   64.1    820   64.6    840   69.1    865
GR  71.1    965   72.6   1065   75.6   1165   77.6   1265   79.1   1365
GR  84.6   1430   90.1   1530
X11050090    31    594    678     35     35     35
GR  84.9      0   78.9    100   74.4    200   72.4    300   67.4    395
GR  60.7    410   57.7    500   57.3    570   57.2    594   52.8    598
GR  51.3    600   50.1    610   50.3    620   50.0    630   49.7    640
GR  49.8    650   49.9    660   52.8    670   59.4    678   61.1    690
GR  61.4    725   64.1    760   64.6    780   69.1    805   71.1    905
GR  72.6   1005   75.6   1105   77.6   1205   79.1   1305   84.6   1370
GR  90.1   1470
NC  0.09   0.09   0.04    0.1    0.3
X11052045    30    780    848   1955   1955   1955
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GR0092.0000000.0 00088.0000060.5 00083.8000163.9 00082.3000240.4 00079.8000263.8
GR0080.0000285.5 00077.0000328.4 00074.6000424.5 00072.8000479.4 00067.9000540.0
GR0063.8000613.3 00061.7000644.8 00059.7000701.3 00059.7000762.1 00059.2000780.0
GR0054.7000789.1 00053.3000790.0 00052.8000790.1 00051.6000792.9 00050.8000810.0
GR0051.0000819.1 00053.3000827.0 00057.3000838.0 00059.7000848.0 00067.4000968.1
GR0068.7000980.2 00079.6000994.7 00089.5001008.7 00091.4001015.7 00092.0001039.6
X1052855      34     676     744     810     810     810
GR0092.0000000.0 00086.9000036.7 00084.2000069.5 00081.4000106.2 00080.6000130.7
GR0080.4000145.8 00080.4000158.5 00080.4000177.7 00080.3000183.6 00078.9000232.1
GR0078.4000300.6 00078.3000353.1 00076.9000413.5 00074.0000459.8 00070.5000504.9
GR0067.3000553.8 00066.6000590.3 00063.2000616.3 00063.5000658.8 00062.2000676.0
GR0056.8000686.0 00054.5000689.0 00053.1000701.1 00052.6000710.0 00053.9000726.0
GR0055.3000731.9 00064.7000744.0 00066.3000754.0 00066.3000764.7 00074.8000875.0
GR0075.5000887.8 00075.5000912.4 00078.8000932.2 00092.0000953.5
X1 53155      16    1066    1121     300     300     300
GR    80       0      76     100      72     220      68     850      64     930
GR    60    1050    60.5    1066    56.1    1088    55.6    1097    56.9    1113
GR  61.3    1121      64    1140      76    1320      80    1350      84    1370
GR    88    1395
NC  0.09    0.09    0.04     0.3     0.5
X1 53205       0       0       0      50      50      50       0      .2
X3    10                                                67      67
SB  1.05    1.56     2.8             63.4       7     972    3.33    55.8    55.8
X1 53244      24     900    1034      39      39      39
X2                     1    66.4      68
X3    10                                                68      68
BT    24       0    89.0    89.0     100    84.0    84.0     200    79.0    79.0
BT   300    74.0    74.0     400    70.0    70.0     500    68.0    68.0     600
BT  69.0    69.0     700    71.0    71.0     800    73.0    73.0     900    74.0
BT  74.0     901    76.2    66.4     915    76.2    66.3     923    76.2    66.2
BT   957    76.2    66.1     972    76.2    66.2     984    76.2    66.2    1033
BT  76.2    66.0    1034    74.0    74.0    1134    74.5    74.5    1234    78.0
BT  78.0    1334    84.0    84.0    1434    89.5    89.5    1534    95.0    95.0
BT  1634    99.0    99.0
GR  89.0       0    84.0     100    79.0     200    74.0     300    70.0     400
GR  68.0     500    69.0     600    71.0     700    73.0     800    74.0     900
GR  60.9     901    60.9     915    56.7     923    59.0     957    55.8     972
GR  58.2     984    59.4    1033    74.0    1034    74.5    1134    78.0    1234
GR  84.0    1334    89.5    1434    95.0    1534    99.0    1634
X1 53280      37    1466    1593      36      36      36
GR  78.0       0    78.0      95    77.8     190    77.5     280    77.0     395
GR  77.0     405    77.0     410    77.0     415    76.5     425    76.8     438
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GR  76.4     750    76.5     925    71.3     950    70.3    1065    68.7    1165
GR  68.2    1265    67.5    1345    67.5    1375    64.7    1435    64.2    1440
GR  59.7    1452    58.2    1466    57.2    1470    56.5    1490    56.4    1510
GR  56.6    1530    56.2    1550    57.2    1570    57.7    1590    58.2    1593
GR  60.3    1606    70.4    1616    73.9    1690    76.1    1740    88.4    1890
GR 104.7    1970     120    2060
X1053320      38    1547    1705      40      40      40
GR  78.0       0    78.0      95    77.8     190    77.5     280    77.0     395
GR  77.0     405    77.0     410    77.0     415    76.5     425    76.8     438
GR  76.4     750    76.5     925    71.3     950    70.3    1065    68.7    1165
GR  68.2    1265    67.5    1345    67.5    1375    64.7    1435    65.4    1537
GR  69.1    1538    68.2    1547    62.4    1548    62.4    1580    62.4    1605
GR  62.4    1630    62.4    1655    62.6    1682    64.2    1695    69.0    1705
GR  71.3    1735    73.5    1780    76.1    1837    79.4    1911    88.4    1996
GR 104.7    2070   112.1    2164   114.7    2237
X1053345      31    1380    1559      25      25      25
GR    78       0    76.8     438    76.4     750    76.5     925    71.3     950
GR  70.3    1065    68.7    1165    68.2    1265    67.5    1345    67.5    1375
GR    67    1380    64.2    1385    59.7    1397    58.2    1411    57.2    1415
GR  56.5    1435    56.4    1455    56.6    1475    56.2    1495    57.2    1515
GR  57.7    1535    58.2    1538    60.3    1551      67    1559      69    1605
GR  71.3    1635    73.5    1680    76.1    1737    79.4    1811    88.4    1896
GR 104.7    1970
NC     0       0       0      .1      .3
X1055360      38    1232  1329.1    2015    2015    2015
GR0096.1000000.0 00093.4000038.4 00090.5000109.0 00088.1000160.9 00084.2000222.3
GR0082.3000275.7 00080.6000328.6 00080.2000389.4 00080.6000453.6 00079.7000463.4
GR0079.7000479.8 00079.7000486.8 00079.2000518.1 00077.5000539.5 00076.1000631.4
GR0076.1000702.4 00075.2000771.5 00073.1000830.4 00070.2000911.4 00068.3001002.8
GR0068.2001085.9 00068.2001170.7 00068.2001215.4 00068.2001232.0 00063.1001238.1
GR0062.2001238.2 00060.8001246.0 00060.7001267.9 00060.2001292.1 00063.1001311.0
GR0065.6001317.0 00075.5001329.1 00076.3001344.2 00076.3001355.3 00081.4001371.6
GR0085.9001391.2 00089.6001415.2 00096.0001439.7
X1 55713      19      40   139.9     353     353     353
GR 83.81       0   78.71      40   77.62      40   73.44    44.5   68.71    48.5
GR 63.71    50.2   62.87    60.2   62.87    70.2   62.96    80.2   63.21    90.2
GR 63.31   100.2   62.75   110.2   62.58   120.2   63.95   130.2   67.25   133.1
GR 71.05   139.9   71.50   153.1   69.30   173.1   70.06   193.1
X1 56623      13      40   119.2     910     910     910
GR 69.97       0   70.21      20   71.43      40   68.07    46.0   64.36    50.6
GR 63.40    60.6   62.57    70.6   63.09    80.6   64.35    89.2   64.25   106.2
GR 71.10   119.2   71.89   139.2   79.14   159.2
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X1 57000        24       801       880       377       377       377
GR    96         0        92       120        88       190        84       320        80       510
GR    76       760        72       761        68       801      65.4       805      64.5       806
GR  63.1       814        63       833      62.5       847      65.4       870      67.9       875
GR    68       880        72       900        73       950        76      1300        80      1325
GR    84      1335        88      1345        92      1360        96      1390
X1 57030        15        40     121.1        30        30        30
GR 71.72         0     70.90        20     73.11        40     68.67        46     66.47      54.1
GR 65.18      56.4     63.66      66.4     63.70      76.4     64.10      86.4     64.29      96.4
GR 64.54     106.4     64.90     116.1     66.98     119.3     71.53     121.1     70.51     141.1
X1 57970        15        40     130.4       940       940       940
GR 72.40         0     72.80        20     74.93        40     73.27     51.60     70.54      57.6
GR 66.56      65.9     65.26      75.9     65.68      85.9     65.64     95.90     66.12     105.9
GR 66.50     110.4     67.92     117.4     71.07     123.3     75.14     130.4     78.20     150.4
X1058305        24       122       253       335       335       335
GR 116.8         0     108.8        20     100.8        41      87.5        70      83.2       100
GR  79.5       105      78.2       106      76.5       122      68.6       124      67.1       140
GR  65.7       160      64.4       180      64.5       200      65.7       220      67.9       240
GR  69.2       245      74.3       253      74.8       320      74.9       380        75       460
GR  77.5       500        81       600        89       800        97      1000
NC     0         0         0        .3        .5
X1 58345        38       135       527        40        40        40         0
GR 116.8         0     108.8        20     100.8        41      87.5        70      83.2       100
GR  79.0       135      79.0       155      74.8       156      74.7       180      74.5       205
GR  74.6       230      74.6       256      75.2       257      75.2       258      74.7       272
GR  74.7       289      74.7       293      74.7       305      74.7       347      74.8       402
GR  74.8       412      74.9       482      77.4       527      79.6       582      81.7       637
GR  84.2       722      86.6       772      89.0       822      90.3       852      91.6       862
GR  91.7       872      91.2       882      92.4       889      94.3       972      98.9      1064
GR 104.1      1164     110.0      1264     116.2      1366
X1 58375        35       125       238        30        30        30         0       0.0
GR 116.8         0     108.8        20     100.8        41      87.5        70      83.2       100
GR  79.5       105      78.1       106      77.7       125      72.9       128      72.2       145
GR  71.0       165      72.7       185      72.9       205      73.6       225      74.9       235
GR  77.4       238      77.4       262      77.4       263      77.4       300      77.4       301
GR  79.6       400      81.7       500      84.2       550      86.6       560      89.0       580
GR  90.3       610      91.6       620      91.7       630      91.2       640      92.4       647
GR  94.3       730      98.9       822     104.1       922     110.0      1022     116.2      1124
NC     0         0         0        .1        .3
X1060120        46       517       591      1745      1745      1745
GR0112.0000000.0 00099.7000024.6 00094.0000041.8 00087.4000062.7 00081.4000085.0
GR0079.0000105.2 00077.5000135.8 00079.2000143.0 00079.5000187.7 00079.4000247.6
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GR0079.5000284.6 00080.3000320.1 00080.7000357.8 00079.3000375.2 00080.1000401.5
GR0078.3000414.9 00080.6000430.7 00080.7000460.2 00080.6000482.8 00079.2000501.5
GR0078.8000517.0 00075.7000521.9 00072.7000522.1 00072.1000531.0 00072.8000541.0
GR0073.1000554.0 00073.6000571.0 00075.7000585.0 00082.1000591.0 00082.1000615.0
GR0080.2000663.7 00080.2000704.1 00079.8000738.7 00085.6000769.1 00088.8000795.1
GR0088.6000813.8 00087.3000825.9 00091.5000842.3 00091.2000858.6 00091.2000875.6
GR0097.1000890.5 00097.8000920.7 00100.5000969.8 00103.2001000.9 00106.5001051.7
GR0112.0001111.4
X1061250      21     772     863    1130    1130    1130
GR   112       0     100     160      92     300      84     360      84     720
GR  87.7     740    87.6     760    85.8     772    75.3     782    75.1     790
GR  75.1     800    75.1     810    73.8     820    74.3     830    74.3     840
GR  75.3     850    81.7     863    82.4     890      92     910     100     980
GR   112    1100
X1061270      20     775     877      20      20      20
GR   112       0     100     160      92     300      84     360      84     720
GR  87.7     740    87.9     762    85.4     775    76.6     785    76.5     799
GR  76.8     819    76.2     834    76.8     854    77.2     871    81.9     877
GR  82.0     891    82.4     899      92     919     100     989     112    1109
X1061300      26     760     971      30      30      30
GR   112       0     100     160      92     300      84     360      84     720
GR  87.7     740    86.8     760    82.8     765    80.8     778    76.3     883
GR  75.9     890    75.9     900    75.9     910    75.4     920    75.0     930
GR  74.3     940    73.7     950    74.3     960    76.3     970    82.7     971
GR  84.2     980    82.3     983    82.3     990      92    1010     100    1080
GR   112    1200
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PAGE 1

THIS RUN EXECUTED 06-06-95

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  HEC2 RELEASE DATED NOV 76 UPDATED MAY  1984
  ERROR CORR -  01,02,03,04,05,06
  MODIFICATION -  50,51,52,53,54,55,56
  IBM-PC-XT VERSION AUGUST 1985
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T1 WHITE CLAY CREEK AT NEWARK
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 11.27 CFS = 7.3 MGD

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	-10.	6.	0.	0.	.000000	.00	.0	0.	46.700	.000

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1.000	.000	-1.000	.000	.000	.000	.000	.000	.000	.000

J3 VARIABLE CODES FOR SUMMARY PRINTOUT

38.000	43.000	42.000	1.000	8.000	26.000	4.000	.000	.000	.000

SUMMARY PRINTOUT

	SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
	49000.000	11.30	45.70	46.70	1.00	.46	35.09
*	50000.000	11.30	47.40	48.01	.61	2.65	20.63
*	50055.000	11.30	52.00	52.34	.34	2.35	28.36
	50090.000	11.30	49.70	52.45	2.75	.07	70.33
	52045.000	11.30	50.80	52.46	1.66	.28	33.20
*	52855.000	11.30	52.60	53.11	.51	2.91	15.21
	53155.000	11.30	55.60	56.34	.74	1.42	19.35
	53205.000	11.30	55.80	56.56	.76	1.34	19.78
	53244.000	11.30	55.80	56.57	.77	3.93	7.46
	53280.000	11.30	56.20	56.91	.71	.32	86.04
*	53320.000	11.30	62.40	62.47	.07	1.47	116.31
	53345.000	11.30	56.20	62.51	6.31	.01	164.14

	55360.000	11.30	60.20	62.51	2.31	.10	69.01
*	55713.000	11.30	62.58	62.97	.39	2.07	38.00
	56623.000	11.30	62.57	63.87	1.30	.50	30.29
	57000.000	11.30	62.50	63.92	1.42	.26	48.96
*	57030.000	11.30	63.66	63.97	.31	2.69	18.91

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06-06-95 16:10:01
PAGE 9

	SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
	57970.000	11.30	65.26	66.18	.92	.61	37.69
	58305.000	11.30	64.40	66.19	1.79	.14	71.36
*	58345.000	11.30	74.50	74.67	.17	1.72	72.25
	58375.000	11.30	71.00	74.73	3.73	.05	106.83
	60120.000	11.30	72.10	74.73	2.63	.12	56.58
	61250.000	11.30	73.80	74.75	.95	.72	31.65
*	61270.000	11.30	76.20	76.60	.40	2.00	43.65

APPENDIX D

HEC-2 Model Input/Output

White Clay Creek at Stanton

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T1 WHITE CLAY CREEK AT STANTON
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 26.6 CFS = 17.2 MGD, Low Tide Elevation = -1.53 ft.
J1   -10        7        0        0        0        0        0        0    -1.53
J2    -1        0                 0
J3    38       43       42        1        8       26        4
NC  .090     .090     .035       .1       .3
QT    15      8.8      9.3     17.3     21.0     22.8     26.6     42.1     73.0     84.1
QT    12       15       32       38       50       60
X1  2600       23      680      900        0        0        0
GR    16        0       12       50        8      100       12      400       12      500
GR     8      650        4      680        3      710       .2      720      -.2      730
GR  -5.4      740     -5.5      780     -5.5      800     -5.2      840     -1.8      850
GR  -1.0      860       .6      870        2      890        4      900        8      950
GR     8      970      1.1     1000      1.0     2000
X1  5050       63     3049   3213.8     2450     2450     2450
GR 022.5000393.3   022.7000480.0   023.1000563.8   021.1000642.6   019.3000720.4
GR 016.0000819.1   015.2000893.5   016.0000969.8   012.2001041.0   008.9001138.8
GR 006.7001241.5   007.2001317.6   004.9001415.0   004.0001516.8   003.5001660.6
GR 004.0001733.5   004.9001828.3   004.7001916.7   003.4002014.7   002.5002081.7
GR 003.1002136.1   003.4002286.2   003.8002413.8   004.3002579.0   003.9002726.3
GR 003.9002855.1   005.2002925.7   004.5002981.4   006.0003049.0   002.1003057.1
GR-001.6003067.1  -000.9003093.9  -000.9003112.0  -001.4003135.1  -001.4003158.9
GR 002.1003179.1   022.5003213.8   024.9003269.3   027.0003330.9   027.4003393.0
GR 028.0003468.3   028.0003537.1   028.0003600.3   028.0003643.0   028.0003692.8
GR 028.0003776.1   028.0003839.7   028.0003916.0   028.0003980.8   028.0004029.3
GR 028.0004058.6   028.0004084.6   028.0004150.5   028.0004212.3   028.0004265.1
GR 028.0004308.4   028.0004341.6   032.3004380.5   032.0004440.0   032.8004504.7
GR 034.1004571.4   036.7004640.3   040.0004695.2
X1005425                                    375      375      375
X1  6200       32     1794     1921      650      850      775
GR  6.48        0     6.08      212     6.12      282     6.52      354     6.44      414
GR  6.05      491     6.32      627     6.03      780     4.29      839     3.97      998
GR  4.39     1134     5.06     1276     3.77     1427     4.07     1607     3.94     1670
GR  4.23     1766     7.36     1784     6.95     1794     0.88     1797    -1.22     1806
GR -0.56     1835    -1.90     1871    -2.49     1894    -0.27     1914    -5.17     1921
GR  4.90     1930     1.59     1937     2.36     1943     5.22     1950     4.99     2076
GR  5.74     2164    11.56     2562
X1  7900       35     2675     2832     1600     1000     1700
GR  9.83        0     9.13      113    11.70      249    12.21      332     8.29      396
GR  9.08      478     8.89      503     7.57      605     8.17      722    11.54      922
GR  8.77     1007     5.22     1249     4.86     1359     4.39     1530     4.60     1675
```

GR	4.41	1815	4.90	1969	2.60	2124	4.04	2294	4.83	2431
GR	6.79	2675	3.15	2680	-2.32	2693	-2.60	2701	-1.45	2720
GR	-0.20	2756	1.78	2760	0.18	2803	2.96	2829	7.20	2832
GR	7.70	2838	6.06	2974	4.95	3067	8.85	3076	14.51	3132
X1	9800	13	1750	1875	4375	4375	4375			
GR	12	0	8	40	8	1650	8	1750	6	1755
GR	2.1	1758	-1.4	1762	-1.4	1858	2.1	1865	16	1875
GR	20	1900	24	1950	36	2050				
X1	10800	40	2490	2591	900	1000	1000			
GR	15.22	0	15.94	64	14.50	108	11.81	131	11.18	159
GR	9.85	209	9.34	297	12.28	322	8.17	374	7.56	511
GR	8.21	585	7.09	724	7.71	775	5.56	786	8.83	797
GR	8.94	817	6.72	905	7.69	1077	7.42	1229	7.29	1324
GR	6.56	1520	6.48	1603	6.65	1711	5.99	1901	6.57	2082
GR	7.03	2207	8.38	2314	6.91	2322	8.31	2327	7.79	2386
GR	8.94	2399	7.95	2490	1.52	2503	-1.00	2545	-1.10	2565
GR	0.65	2572	-0.20	2576	1.32	2581	8.17	2591	14.09	2649
X1	10900	33	3091	3194	1100	1100	1100			
GR	15	0	14	171	13	342	12	514	10	857
GR	8	1200	8	1500	8	1800	8	2100	8	2400
GR	6.8	2700	6.5	2750	6.9	2801	7.4	2850	8.3	2897
GR	7.3	2900	8.4	2950	9.2	3001	9.4	3051	8.2	3091
GR	4.8	3099	4.9	3101	2.1	3106	-0.3	3153	-0.9	3164
GR	-1.7	3172	-0.1	3183	8.5	3194	9.3	3204	12.5	3232
GR	15.9	3259	19.4	3287	19.2	3295				
X1	11436	38	2603	2720	460	580	536			
GR	15	0	14	171	13	342	12	514	10	857
GR	8	1200	8	1400	8	1600	8	1800	8	2000
GR	6.9	2200	7.5	2250	8.1	2300	8.4	2350	8.4	2400
GR	8.4	2450	8.8	2500	8.1	2521	10.2	2535	9.0	2560
GR	8.8	2603	2.5	2615	-0.2	2675	-2.1	2700	22.2	2710
GR	9.3	2720	9.1	2725	8.9	2758	10.1	2808	11.3	2858
GR	10.7	2908	9.7	2958	10.0	3008	10.0	3058	11.3	3108
GR	12.4	3167	13.66	3212	14.0	3223				
X1	12320	36	1000	1100	1520	1300	1520			
GR	10.25	0	10.10	50	9.95	100	9.62	200	9.28	300
GR	9.27	400	8.95	500	8.70	600	8.38	700	8.68	800
GR	4.98	830	7.98	900	8.38	1000	1.28	1005	-1.15	1050
GR	1.78	1095	7.93	1100	7.88	1200	7.60	1300	8.65	1400
GR	13.43	1480	13.73	1600	13.81	1700	13.89	1800	13.96	1825
GR	33.96	1826	33.96	1900	33.96	2000	33.96	2100	33.96	2200

GR	33.96	2216	13.96	2217	13.96	2220	10.09	2225	9.79	2300
GR	12.72	2400								
X1	12560	20	1550	1800	2760	2760	2760			
GR	18.3	0	16	200	16	1100	16	1550	5.4	1552
GR	2.1	1555	.2	1559	-.8	1566	-1	1575	-1.23	1581
GR	-1.33	1690	1	1706	1.6	1708	2.8	1712	7.6	1722
GR	16.0	1800	16	2000	16	2050	16	2550	20	2750
NC	0	0	0	.3	.5					
X1	12660	22	1000	1251	100	100	100			
X3	10							19.6	19.6	
GR	24.6	0	19.6	1000	9.8	1001	9.8	1049	6.1	1055
GR	6.1	1059	5.3	1065	5.3	1110	1.6	1113	1.6	1123
GR	6.6	1129	6.6	1154	-1.3	1156	-1.3	1187	-0.9	1193
GR	-0.9	1208	-0.7	1222	-0.2	1236	7.1	1248	7.1	1250
GR	19.6	1251	24.6	2251						
SB	1.05	1.56	2.8		66	18	1750	7.36	-1.3	-1.3
X1	12703				43	43	43			
X2			1	11.2	19.6					
X3	10							19.6	19.6	
BT	22	0	24.6	24.6	1000	19.6	19.6	1001	22.1	11.2
BT	1049	22.1	11.2	1055	22.1	11.2	1059	22.1	11.2	1065
BT	22.1	11.2	1110	22.1	11.2	1113	22.1	11.2	1123	22.1
BT	11.2	1129	22.1	11.2	1154	22.1	11.2	1156	22.1	11.2
BT	1187	22.1	11.2	1193	22.1	11.2	1208	22.1	11.2	1222
BT	22.1	11.2	1236	22.1	11.2	1248	22.1	11.2	1250	22.1
BT	11.2	1251	19.6	19.6	2251	24.6	24.6			
X1	12753	0	0	0	50	50	50			
X1	12873	45	1068	1201	47	447	120			
GR	24.6	0	19.6	1000	10	1040	8	1051	7	1068
GR	5	1071	3	1076	-0.66	1129	3	1181	5	1190
GR	8	1201	9	1246	10	1263	15	1271	15.2	1275
GR	15	1279	13	1284	12.5	1285	12.5	1340	12.5	1400
GR	12.5	1415	12.5	1430	13	1431	14	1434	14.8	1440
GR	14	1447	10	1453	9	1536	9	1561	10	1568
GR	8	1628	7	1715	7	1903	8	1973	8	2028
GR	8	2092	9	2179	9	2272	9	2540	10	2640
GR	11	2720	12	2755	13	2794	14	2815	15	2819
X1	13448	10	586	703	575	575	575			
GR	11	586	10	591	9.5	604	3	605	0.57	636
GR	3	668	9	679	9	691	9	697	10	703
X1	13843	80	881	980	395	395	395			
GR	20.9	0	20.1	202	20	263	19	325	18	388

GR	17	417	16	449	15	458	12	473	11	631
GR	10	686	10	707	11	769	12	793	11	825
GR	10	838	9	866	8	874	7	881	3	887
GR	1.6	929	3	970	5	974	10	980	12	1002
GR	12	1028	12	1074	12	1117	12.8	1140	12	1152
GR	11.5	1156	11.5	1247	11.5	1297	12	1304	12.8	1318
GR	12	1335	11.5	1345	11.5	1369	11.5	1387	11.5	1430
GR	11.5	1462	12	1484	12.5	1492	13	1503	14	1505
GR	15	1507	15	1510	15.5	1512	15	1515	13	1520
GR	12.5	1521	12.5	1545	12.5	1570	12.5	1600	12.5	1614
GR	12.5	1628	13	1631	14	1634	14.8	1640	14	1643
GR	14	1647	10	1653	9	1736	9	1761	10	1768
GR	8	1828	7	1915	7	2003	8	2073	8	2228
GR	8	2292	9	2379	9	2472	9	2740	10	2840
GR	11	2929	12	2955	13	2994	14	3015	15	3019
X1	13955	68	1324	1403.1	1202	1202	1202	0	-1.3	
GR	40	0	38.3	31.2	37.2	72.2	35.5	113.9	33.9	148.8
GR	33	155	31	228	19.9	259	14	271	13.2	329
GR	11	365	9.5	435	8.8	491	10	555	7.3	589
GR	8.2	608	7.5	680	7.7	761	8	827	9.1	884
GR	7.1	902	7.8	982	8.5	1038	8.5	1098	7.4	1144
GR	7.6	1199	9.8	1290	9.7	1324	8.7	1329	8.4	1332
GR	5.1	1336	3.2	1337	2.2	1346	1.9	1354	1.7	1362
GR	1.6	1370	3	1387	4.6	1387.1	5.8	1393	10.6	1403.1
GR	10.6	1422	10.5	1463	10	1525	10.8	1600	11	1655
GR	10.2	2049	10.3	2131	11.5	2156	7.7	2170	12.8	2197
GR	9.9	2216	12	2254	11	2293	13	2317	13.5	2356
GR	11.9	2409	11.1	2424	8.6	2440	8.7	2451	4.7	2468
GR	4.7	2475	9.5	2481	9.7	2493	9.7	2511	16	2534
GR	17.9	2551	20.5	2560	21	2614				
NC	0.08	0.095	0.04	.1	.3					
X1	14073	10	807	903	118	118	118			
GR	12	807	10	816	5	825	4	831	4	834
GR	1.71	850	3	866	5	869	9	875	9	903
X1	14990	0	0	0	971	971	971	0	1.3	
NC	0	0	0	.3	.5					
X1	15890	30	1000	1120	900	900	900			
GR	32.3	0	29.8	100	27.3	200	23.8	300	18.8	400
GR	14.8	500	12.3	600	12.8	700	14.8	800	14.8	900
GR	16.3	1000	10.9	1001	8.1	1014	2.5	1026	2.5	1047
GR	2.5	1067	3.5	1081	5.9	1101	8.1	1110	10.4	1119
GR	16.3	1120	14.3	1220	11.3	1320	10.8	1420	11.3	1520

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GR0079.5000284.6 00080.3000320.1 00080.7000357.8 00079.3000375.2 00080.1000401.5
GR0078.3000414.9 00080.6000430.7 00080.7000460.2 00080.6000482.8 00079.2000501.5
GR0078.8000517.0 00075.7000521.9 00072.7000522.1 00072.1000531.0 00072.8000541.0
GR0073.1000554.0 00073.6000571.0 00075.7000585.0 00082.1000591.0 00082.1000615.0
GR0080.2000663.7 00080.2000704.1 00079.8000738.7 00085.6000769.1 00088.8000795.1
GR0088.6000813.8 00087.3000825.9 00091.5000842.3 00091.2000858.6 00091.2000875.6
GR0097.1000890.5 00097.8000920.7 00100.5000969.8 00103.2001000.9 00106.5001051.7
GR0112.0001111.4
X1061250      21     772     863    1130    1130    1130
GR   112       0     100     160      92     300      84     360      84     720
GR  87.7     740    87.6     760    85.8     772    75.3     782    75.1     790
GR  75.1     800    75.1     810    73.8     820    74.3     830    74.3     840
GR  75.3     850    81.7     863    82.4     890      92     910     100     980
GR   112    1100
X1061270      20     775     877      20      20      20
GR   112       0     100     160      92     300      84     360      84     720
GR  87.7     740    87.9     762    85.4     775    76.6     785    76.5     799
GR  76.8     819    76.2     834    76.8     854    77.2     871    81.9     877
GR  82.0     891    82.4     899      92     919     100     989     112    1109
X1061300      26     760     971      30      30      30
GR   112       0     100     160      92     300      84     360      84     720
GR  87.7     740    86.8     760    82.8     765    80.8     778    76.3     883
GR  75.9     890    75.9     900    75.9     910    75.4     920    75.0     930
GR  74.3     940    73.7     950    74.3     960    76.3     970    82.7     971
GR  84.2     980    82.3     983    82.3     990      92    1010     100    1080
GR   112    1200
EJ


ER
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PAGE 1

THIS RUN EXECUTED 06
-06-95

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  HEC2 RELEASE DATED NOV 76 UPDATED MAY  1984
  ERROR CORR -  01,02,03,04,05,06
  MODIFICATION -  50,51,52,53,54,55,56
  IBM-PC-XT VERSION AUGUST 1985
*************************************************
```

T1 WHITE CLAY CREEK AT NEWARK
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 11.27 CFS = 7.3 MGD

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	-10.	6.	0.	0.	.000000	.00	.0	0.	46.700	.000

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1.000	.000	-1.000	.000	.000	.000	.000	.000	.000	.000

J3 VARIABLE CODES FOR SUMMARY PRINTOUT

38.000	43.000	42.000	1.000	8.000	26.000	4.000	.000	.000	.000

SUMMARY PRINTOUT

SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
49000.000	11.30	45.70	46.70	1.00	.46	35.09
* 50000.000	11.30	47.40	48.01	.61	2.65	20.63
* 50055.000	11.30	52.00	52.34	.34	2.35	28.36
50090.000	11.30	49.70	52.45	2.75	.07	70.33
52045.000	11.30	50.80	52.46	1.66	.28	33.20
* 52855.000	11.30	52.60	53.11	.51	2.91	15.21
53155.000	11.30	55.60	56.34	.74	1.42	19.35
53205.000	11.30	55.80	56.56	.76	1.34	19.78
53244.000	11.30	55.80	56.57	.77	3.93	7.46
53280.000	11.30	56.20	56.91	.71	.32	86.04
* 53320.000	11.30	62.40	62.47	.07	1.47	116.31
53345.000	11.30	56.20	62.51	6.31	.01	164.14

	55360.000	11.30	60.20	62.51	2.31	.10	69.01
*	55713.000	11.30	62.58	62.97	.39	2.07	38.00
	56623.000	11.30	62.57	63.87	1.30	.50	30.29
	57000.000	11.30	62.50	63.92	1.42	.26	48.96
*	57030.000	11.30	63.66	63.97	.31	2.69	18.91

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PAGE 9

	SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
	57970.000	11.30	65.26	66.18	.92	.61	37.69
	58305.000	11.30	64.40	66.19	1.79	.14	71.36
*	58345.000	11.30	74.50	74.67	.17	1.72	72.25
	58375.000	11.30	71.00	74.73	3.73	.05	106.83
	60120.000	11.30	72.10	74.73	2.63	.12	56.58
	61250.000	11.30	73.80	74.75	.95	.72	31.65
*	61270.000	11.30	76.20	76.60	.40	2.00	43.65

APPENDIX D

HEC-2 Model Input/Output

White Clay Creek at Stanton

```
T1 WHITE CLAY CREEK AT STANTON
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 26.6 CFS = 17.2 MGD, Low Tide Elevation = -1.53 ft.
J1    -10        7        0        0        0        0        0        0    -1.53
J2     -1        0                 0
J3     38       43       42        1        8       26        4
NC   .090     .090     .035       .1       .3
QT     15      8.8      9.3     17.3     21.0     22.8     26.6     42.1     73.0     84.1
QT     12       15       32       38       50       60
X1   2600       23      680      900        0        0        0
GR     16        0       12       50        8      100       12      400       12      500
GR      8      650        4      680        3      710       .2      720      -.2      730
GR   -5.4      740     -5.5      780     -5.5      800     -5.2      840     -1.8      850
GR   -1.0      860       .6      870        2      890        4      900        8      950
GR      8      970      1.1     1000      1.0     2000
X1   5050       63     3049   3213.8     2450     2450     2450
GR 022.5000393.3   022.7000480.0   023.1000563.8   021.1000642.6   019.3000720.4
GR 016.0000819.1   015.2000893.5   016.0000969.8   012.2001041.0   008.9001138.8
GR 006.7001241.5   007.2001317.6   004.9001415.0   004.0001516.8   003.5001660.6
GR 004.0001733.5   004.9001828.3   004.7001916.7   003.4002014.7   002.5002081.7
GR 003.1002136.1   003.4002286.2   003.8002413.8   004.3002579.0   003.9002726.3
GR 003.9002855.1   005.2002925.7   004.5002981.4   006.0003049.0   002.1003057.1
GR-001.6003067.1  -000.9003093.9  -000.9003112.0  -001.4003135.1  -001.4003158.9
GR 002.1003179.1   022.5003213.8   024.9003269.3   027.0003330.9   027.4003393.0
GR 028.0003468.3   028.0003537.1   028.0003600.3   028.0003643.0   028.0003692.8
GR 028.0003776.1   028.0003839.7   028.0003916.0   028.0003980.8   028.0004029.3
GR 028.0004058.6   028.0004084.6   028.0004150.5   028.0004212.3   028.0004265.1
GR 028.0004308.4   028.0004341.6   032.3004380.5   032.0004440.0   032.8004504.7
GR 034.1004571.4   036.7004640.3   040.0004695.2
X1005425                                    375      375      375
X1   6200       32     1794     1921      650      850      775
GR   6.48        0     6.08      212     6.12      282     6.52      354     6.44      414
GR   6.05      491     6.32      627     6.03      780     4.29      839     3.97      998
GR   4.39     1134     5.06     1276     3.77     1427     4.07     1607     3.94     1670
GR   4.23     1766     7.36     1784     6.95     1794     0.88     1797    -1.22     1806
GR  -0.56     1835    -1.90     1871    -2.49     1894    -0.27     1914    -5.17     1921
GR   4.90     1930     1.59     1937     2.36     1943     5.22     1950     4.99     2076
GR   5.74     2164    11.56     2562
X1   7900       35     2675     2832     1600     1000     1700
GR   9.83        0     9.13      113    11.70      249    12.21      332     8.29      396
GR   9.08      478     8.89      503     7.57      605     8.17      722    11.54      922
GR   8.77     1007     5.22     1249     4.86     1359     4.39     1530     4.60     1675
```

GR	4.41	1815	4.90	1969	2.60	2124	4.04	2294	4.83	2431
GR	6.79	2675	3.15	2680	-2.32	2693	-2.60	2701	-1.45	2720
GR	-0.20	2756	1.78	2760	0.18	2803	2.96	2829	7.20	2832
GR	7.70	2838	6.06	2974	4.95	3067	8.85	3076	14.51	3132
X1	9800	13	1750	1875	4375	4375	4375			
GR	12	0	8	40	8	1650	8	1750	6	1755
GR	2.1	1758	-1.4	1762	-1.4	1858	2.1	1865	16	1875
GR	20	1900	24	1950	36	2050				
X1	10800	40	2490	2591	900	1000	1000			
GR	15.22	0	15.94	64	14.50	108	11.81	131	11.18	159
GR	9.85	209	9.34	297	12.28	322	8.17	374	7.56	511
GR	8.21	585	7.09	724	7.71	775	5.56	786	8.83	797
GR	8.94	817	6.72	905	7.69	1077	7.42	1229	7.29	1324
GR	6.56	1520	6.48	1603	6.65	1711	5.99	1901	6.57	2082
GR	7.03	2207	8.38	2314	6.91	2322	8.31	2327	7.79	2386
GR	8.94	2399	7.95	2490	1.52	2503	-1.00	2545	-1.10	2565
GR	0.65	2572	-0.20	2576	1.32	2581	8.17	2591	14.09	2649
X1	10900	33	3091	3194	1100	1100	1100			
GR	15	0	14	171	13	342	12	514	10	857
GR	8	1200	8	1500	8	1800	8	2100	8	2400
GR	6.8	2700	6.5	2750	6.9	2801	7.4	2850	8.3	2897
GR	7.3	2900	8.4	2950	9.2	3001	9.4	3051	8.2	3091
GR	4.8	3099	4.9	3101	2.1	3106	-0.3	3153	-0.9	3164
GR	-1.7	3172	-0.1	3183	8.5	3194	9.3	3204	12.5	3232
GR	15.9	3259	19.4	3287	19.2	3295				
X1	11436	38	2603	2720	460	580	536			
GR	15	0	14	171	13	342	12	514	10	857
GR	8	1200	8	1400	8	1600	8	1800	8	2000
GR	6.9	2200	7.5	2250	8.1	2300	8.4	2350	8.4	2400
GR	8.4	2450	8.8	2500	8.1	2521	10.2	2535	9.0	2560
GR	8.8	2603	2.5	2615	-0.2	2675	-2.1	2700	22.2	2710
GR	9.3	2720	9.1	2725	8.9	2758	10.1	2808	11.3	2858
GR	10.7	2908	9.7	2958	10.0	3008	10.0	3058	11.3	3108
GR	12.4	3167	13.66	3212	14.0	3223				
X1	12320	36	1000	1100	1520	1300	1520			
GR	10.25	0	10.10	50	9.95	100	9.62	200	9.28	300
GR	9.27	400	8.95	500	8.70	600	8.38	700	8.68	800
GR	4.98	830	7.98	900	8.38	1000	1.28	1005	-1.15	1050
GR	1.78	1095	7.93	1100	7.88	1200	7.60	1300	8.65	1400
GR	13.43	1480	13.73	1600	13.81	1700	13.89	1800	13.96	1825
GR	33.96	1826	33.96	1900	33.96	2000	33.96	2100	33.96	2200

GR	33.96	2216	13.96	2217	13.96	2220	10.09	2225	9.79	2300
GR	12.72	2400								
X1	12560	20	1550	1800	2760	2760	2760			
GR	18.3	0	16	200	16	1100	16	1550	5.4	1552
GR	2.1	1555	.2	1559	-.8	1566	-1	1575	-1.23	1581
GR	-1.33	1690	1	1706	1.6	1708	2.8	1712	7.6	1722
GR	16.0	1800	16	2000	16	2050	16	2550	20	2750
NC	0	0	0	.3	.5					
X1	12660	22	1000	1251	100	100	100			
X3	10							19.6	19.6	
GR	24.6	0	19.6	1000	9.8	1001	9.8	1049	6.1	1055
GR	6.1	1059	5.3	1065	5.3	1110	1.6	1113	1.6	1123
GR	6.6	1129	6.6	1154	-1.3	1156	-1.3	1187	-0.9	1193
GR	-0.9	1208	-0.7	1222	-0.2	1236	7.1	1248	7.1	1250
GR	19.6	1251	24.6	2251						
SB	1.05	1.56	2.8		66	18	1750	7.36	-1.3	-1.3
X1	12703				43	43	43			
X2			1	11.2	19.6					
X3	10							19.6	19.6	
BT	22	0	24.6	24.6	1000	19.6	19.6	1001	22.1	11.2
BT	1049	22.1	11.2	1055	22.1	11.2	1059	22.1	11.2	1065
BT	22.1	11.2	1110	22.1	11.2	1113	22.1	11.2	1123	22.1
BT	11.2	1129	22.1	11.2	1154	22.1	11.2	1156	22.1	11.2
BT	1187	22.1	11.2	1193	22.1	11.2	1208	22.1	11.2	1222
BT	22.1	11.2	1236	22.1	11.2	1248	22.1	11.2	1250	22.1
BT	11.2	1251	19.6	19.6	2251	24.6	24.6			
X1	12753	0	0	0	50	50	50			
X1	12873	45	1068	1201	47	447	120			
GR	24.6	0	19.6	1000	10	1040	8	1051	7	1068
GR	5	1071	3	1076	-0.66	1129	3	1181	5	1190
GR	8	1201	9	1246	10	1263	15	1271	15.2	1275
GR	15	1279	13	1284	12.5	1285	12.5	1340	12.5	1400
GR	12.5	1415	12.5	1430	13	1431	14	1434	14.8	1440
GR	14	1447	10	1453	9	1536	9	1561	10	1568
GR	8	1628	7	1715	7	1903	8	1973	8	2028
GR	8	2092	9	2179	9	2272	9	2540	10	2640
GR	11	2720	12	2755	13	2794	14	2815	15	2819
X1	13448	10	586	703	575	575	575			
GR	11	586	10	591	9.5	604	3	605	0.57	636
GR	3	668	9	679	9	691	9	697	10	703
X1	13843	80	881	980	395	395	395			
GR	20.9	0	20.1	202	20	263	19	325	18	388

GR	17	417	16	449	15	458	12	473	11	631
GR	10	686	10	707	11	769	12	793	11	825
GR	10	838	9	866	8	874	7	881	3	887
GR	1.6	929	3	970	5	974	10	980	12	1002
GR	12	1028	12	1074	12	1117	12.8	1140	12	1152
GR	11.5	1156	11.5	1247	11.5	1297	12	1304	12.8	1318
GR	12	1335	11.5	1345	11.5	1369	11.5	1387	11.5	1430
GR	11.5	1462	12	1484	12.5	1492	13	1503	14	1505
GR	15	1507	15	1510	15.5	1512	15	1515	13	1520
GR	12.5	1521	12.5	1545	12.5	1570	12.5	1600	12.5	1614
GR	12.5	1628	13	1631	14	1634	14.8	1640	14	1643
GR	14	1647	10	1653	9	1736	9	1761	10	1768
GR	8	1828	7	1915	7	2003	8	2073	8	2228
GR	8	2292	9	2379	9	2472	9	2740	10	2840
GR	11	2929	12	2955	13	2994	14	3015	15	3019
X1	13955	68	1324	1403.1	1202	1202	1202	0	-1.3	
GR	40	0	38.3	31.2	37.2	72.2	35.5	113.9	33.9	148.8
GR	33	155	31	228	19.9	259	14	271	13.2	329
GR	11	365	9.5	435	8.8	491	10	555	7.3	589
GR	8.2	608	7.5	680	7.7	761	8	827	9.1	884
GR	7.1	902	7.8	982	8.5	1038	8.5	1098	7.4	1144
GR	7.6	1199	9.8	1290	9.7	1324	8.7	1329	8.4	1332
GR	5.1	1336	3.2	1337	2.2	1346	1.9	1354	1.7	1362
GR	1.6	1370	3	1387	4.6	1387.1	5.8	1393	10.6	1403.1
GR	10.6	1422	10.5	1463	10	1525	10.8	1600	11	1655
GR	10.2	2049	10.3	2131	11.5	2156	7.7	2170	12.8	2197
GR	9.9	2216	12	2254	11	2293	13	2317	13.5	2356
GR	11.9	2409	11.1	2424	8.6	2440	8.7	2451	4.7	2468
GR	4.7	2475	9.5	2481	9.7	2493	9.7	2511	16	2534
GR	17.9	2551	20.5	2560	21	2614				
NC	0.08	0.095	0.04	.1	.3					
X1	14073	10	807	903	118	118	118			
GR	12	807	10	816	5	825	4	831	4	834
GR	1.71	850	3	866	5	869	9	875	9	903
X1	14990	0	0	0	971	971	971	0	1.3	
NC	0	0	0	.3	.5					
X1	15890	30	1000	1120	900	900	900			
GR	32.3	0	29.8	100	27.3	200	23.8	300	18.8	400
GR	14.8	500	12.3	600	12.8	700	14.8	800	14.8	900
GR	16.3	1000	10.9	1001	8.1	1014	2.5	1026	2.5	1047
GR	2.5	1067	3.5	1081	5.9	1101	8.1	1110	10.4	1119
GR	16.3	1120	14.3	1220	11.3	1320	10.8	1420	11.3	1520

```
GR  12.3    1620    13.3    1720    13.3    1820    13.8    1920    12.3    2020
X1 15940       0       0       0      50      50      50
X3    10       0       0       0       0       0       0    10.8    10.8
SB  1.05    1.56     2.8             119            1012             2.5     2.5
X1 15979                              39      39      39
X2                     1    12.9    10.8
X3    10                                                    10.8    10.8
BT    30       0    32.3    32.3     100    29.8    29.8     200    27.3    27.3
BT   300    23.8    23.8     400    18.8    18.8     500    14.8    14.8     600
BT  12.3    12.3     700    12.8    12.8     800    14.8    14.8     900    14.8
BT  14.8    1000    16.3    16.3    1001    19.3    12.9    1014    19.3    12.9
BT  1026    19.3    12.9    1047    19.3    12.9    1067    19.3    12.9    1081
BT  19.3    12.9    1101    19.3    12.9    1110    19.3    12.9    1119    19.3
BT  12.9    1120    16.3    16.3    1220    14.3    14.3    1320    11.3    11.3
BT  1420    10.8    10.8    1520    11.3    11.3    1620    12.3    12.3    1720
BT  13.3    13.3    1820    13.3    13.3    1920    13.8    13.8    2020    12.3
BT  12.3
X1 16180      20     950    1475     201     201     201       0     0.0       0
GR0040.0000000.0 00036.0000150.0 00032.0000250.0 00028.0000350.0 00023.4000450.0
GR0027.1000950.0 00022.1000951.0 00009.9000968.0 00010.0001038.0 00012.0001154.0
GR0012.5001269.0 00011.5001311.0 00003.1001316.0 00003.1001360.0 00004.9001361.0
GR0008.0001383.0 00011.0001441.0 00028.0001474.0 00032.0001475.0 00051.1002875.0
X1 16270      20     950    1475      90      90      90
X3    10                                                    23.4    23.4
GR0040.0000000.0 00036.0000150.0 00032.0000250.0 00028.0000350.0 00023.4000450.0
GR0027.1000950.0 00022.1000951.0 00009.9000968.0 00010.0001038.0 00012.0001154.0
GR0012.5001269.0 00011.5001311.0 00003.1001316.0 00003.1001360.0 00004.9001361.0
GR0008.0001383.0 00011.0001441.0 00028.0001474.0 00032.0001475.0 00051.1002875.0
SB  1.05    1.56     2.8             213      14    7274    4.46     3.1     3.1
X1 16380                             110     110     110
X2                     1    27.0    23.4
X3    10                                                    23.4    23.4
BT    20       0      40      40     150      36      36     250      32      32
BT   350      28      28     450    23.4    23.4     950    27.1    27.1     951
BT  30.1    22.1     968    30.3    22.3    1038    30.9    22.9    1154    32.0
BT  24.0    1269    33.0    25.0    1311    33.5    25.5    1316    33.5    25.5
BT  1360    33.9    25.9    1361    33.9    25.9    1383    34.1    26.1    1441
BT  34.7    26.7    1474    35.0    27.0    1475    32.0    32.0    2875    51.1
BT  51.1
X1 16430                              50      50      50
NC     0       0       0      .1      .3
X1 17000      16    1085    1220     570     570     570
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GR    36       0      32     600      31     900      28    1000      24    1010
GR    20    1020      16    1040      12    1045    11.5    1085     3.1    1089
GR   3.1    1143     4.9    1144       8    1166      11    1220      26    1360
GR    51    2300
X1 18000      65    1986    2075    1000    1000    1000               -.5
GR0025.5000862.7 00023.9000909.2 00023.1000966.6 00022.0000979.8 00021.9000987.3
GR  20.4  1015.3    17.0  1034.9    15.0  1676.9    14.0    1986    13.9    1987
GR   8.4  2011.1     7.1    2012       6    2013     6.3  2017.9     6.4  2024.9
GR   6.9  2036.9     7.2    2056       6  2061.9     8.4    2066    16.6    2075
GR  21.8  2414.3    22.2  2432.5   22.21  2432.6   22.22  2432.7   22.23  2432.8
GR0021.7002667.9 00022.3002711.5 00023.5002765.3 00024.4002794.2 00025.5002836.5
GR0026.0002881.3 00025.8002925.1 00026.4002950.6 00026.0002979.6 00026.8003021.0
GR0027.1003060.1 00025.3003088.6 00024.1003120.5 00023.6003145.6 00024.0003186.8
GR0023.8003235.9 00026.0003278.3 00026.0003309.7 00026.5003341.4 00026.7003373.3
GR0028.0003401.8 00029.0003432.6 00029.8003463.6 00029.5003499.8 00029.4003544.4
GR0029.8003602.0 00029.8003655.8 00030.7003720.9 00031.6003746.8 00032.5003792.7
GR0032.6003824.2 00031.6003845.5 00030.7003875.0 00031.9003899.9 00032.7003946.7
GR0033.2003982.0 00034.3004020.0 00036.1004049.8 00036.4004110.8 00036.9004147.8
X1 18700       0       0       0     700     700     700       0      .5
X1 21000      20     765     837    2300    2300    2300
GR    32       0      28     300      24     450      20     670      16     760
GR    14     765     8.4     775       7     776     5.7     777     6.0     781
GR   6.1     788     6.6     796     6.9     816     5.7     821     8.2     827
GR  15.6     837      16     845      16    1365      20    1400      24    1800
EJ


ER
```

THIS RUN EXECUTED 06-01-95

```
*************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED MAY  1984
  ERROR CORR -  01,02,03,04,05,06
  MODIFICATION -  50,51,52,53,54,55,56
  IBM-PC-XT VERSION AUGUST 1985
*************************************************
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T1 WHITE CLAY CREEK AT STANTON
T2 INSTREAM FLOW NEEDS ANALYSIS
T3 MODEL THE 7Q10 = 26.6 CFS = 17.2 MGD, Low Tide Elevation = -1.53 ft.

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	-10.	7.	0.	0.	.000000	.00	.0	0.	-1.530	.000

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

J3 VARIABLE CODES FOR SUMMARY PRINTOUT

38.000	43.000	42.000	1.000	8.000	26.000	4.000	.000	.000	.000

5.
SECNO CUMDIS

1
06-01-95 07:45:03
PAGE 9

THIS RUN EXECUTED 06
-01-95
****
HEC2 RELEASE DATED NOV 76 UPDATED MAY 1984
ERROR CORR - 01,02,03,04,05,06
MODIFICATION - 50,51,52,53,54,55,56
IBM-PC-XT VERSION AUGUST 1985
****

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

THE 7Q10 = 26.6 CFS = 1

SUMMARY PRINTOUT

SECNO Q ELMIN CWSEL DEPTH VCH TOPWID

2600.000	26.60	-5.50	-1.53	3.97	.06	120.82
* 5050.000	26.60	-1.60	-1.18	.42	2.56	52.91
5425.000	26.60	-1.60	-.66	.94	.51	98.66
6200.000	26.60	-5.17	-.58	4.59	.25	117.22
7900.000	26.60	-2.60	-.49	2.11	.43	59.12
9800.000	26.60	-1.40	-.27	1.13	.24	99.53
10800.000	26.60	-1.10	-.20	.90	1.12	36.77
10900.000	26.60	-1.70	.34	2.04	.65	43.04
11436.000	26.60	-2.10	.45	2.55	.58	40.43
12320.000	26.60	-1.15	.68	1.83	.47	62.01
12560.000	26.60	-1.33	.71	2.04	.10	146.04
12660.000	26.60	-1.30	.71	2.01	.20	82.01
12703.000	26.60	-1.30	.71	2.01	.20	82.00
12753.000	26.60	-1.30	.71	2.01	.20	82.00
12873.000	26.60	-.66	.70	1.36	.99	39.29

13448.000	26.60	.57	1.64	1.07	1.78	27.84
13843.000	26.60	1.60	2.56	.96	.97	57.01

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SECNO	Q	ELMIN	CWSEL	DEPTH	VCH	TOPWID
13955.000	26.60	.30	2.66	2.36	.29	50.46
* 14073.000	26.60	1.71	2.56	.85	3.76	16.56
14990.000	26.60	3.01	4.75	1.74	.94	28.87
15890.000	26.60	2.50	4.81	2.31	.20	70.79
15940.000	26.60	2.50	4.81	2.31	.20	70.91
15979.000	26.60	2.50	4.81	2.31	.20	70.83
16180.000	26.60	3.10	4.81	1.71	.35	45.97
16270.000	26.60	3.10	4.81	1.71	.35	45.97
16380.000	26.60	3.10	4.82	1.72	.34	45.97
16430.000	26.60	3.10	4.82	1.72	.34	45.98

	17000.000	26.60	3.10	4.84	1.74	.28	55.80
*	18000.000	26.60	5.50	6.20	.70	3.32	24.30
	18700.000	26.60	6.00	7.46	1.46	.67	52.66
	21000.000	26.60	5.70	7.82	2.12	.39	50.71

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SUMMARY OF ERRORS AND SPECIAL NOTES

CAUTION SECNO= 5050.000 PROFILE= 1 CRITICAL DEPTH ASSUMED
CAUTION SECNO= 5050.000 PROFILE= 1 PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO= 5050.000 PROFILE= 1 20 TRIALS ATTEMPTED TO BALANCE WSEL

CAUTION SECNO= 14073.000 PROFILE= 1 CRITICAL DEPTH ASSUMED
CAUTION SECNO= 14073.000 PROFILE= 1 PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO= 14073.000 PROFILE= 1 20 TRIALS ATTEMPTED TO BALANCE WSEL

CAUTION SECNO= 18000.000 PROFILE= 1 CRITICAL DEPTH ASSUMED
CAUTION SECNO= 18000.000 PROFILE= 1 PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO= 18000.000 PROFILE= 1 20 TRIALS ATTEMPTED TO BALANCE WSEL

APPENDIX E

Supplemental Field Survey Data

by Tetra-Tech, April 1995

The scope of the field investigation was to collect sufficient data to depict cross-sectional profiles of major surface water channels within New Castle County, Delaware. During the March 10th site reconnaissance meeting for the project, ten locations were selected by representatives from DNREC Division of Water Resources, DNREC Division of Fish and Wildlife, and the Water Resources Agency for New Castle County.

- Four locations were selected within an approximate 0.6-mile reach of the White Clay Creek immediately downstream of an existing diversion dam. These locations were estimated (at that time) to be: WWC#1 (W1), 57 + 800 river feet (RF); WWC#2 (W2), 57 + 000 RF; WCC#3 (W3), 56 + 000 RF; and WWC#4 (W4), 55 + 000 RF.

- Two locations were selected within a relatively short reach of the Christina River between the Smalleys Dam and the Smalleys Dam Bridge. These locations were estimated to be: CR#1 (C1), 60 + 000 RF; and CR#2 (C2), 59 + 400 RF.

- Four locations were selected within an approximately 0.4-mile reach of the Brandywine Creek, which is bisected by the I-95 overpass. These location were estimated to be: BW#1 (B1), 2.9 river mile (RM); BW#2 (B2), 2.7 RM; BW#3 (B3), 2.6 RM; and BW#4 (B4), 2.5 RM.

The locations were selected based on existing data gaps identified in the hydrologic model, existing stream substrate, observed characteristics of the stream channel, and stream flows observed during the reconnaissance. Each location was staked during the reconnaissance. In addition, at each location, sufficient field documentation was collected to enable the project manager to re-establish the location should the stake be removed. A detailed cross-sectional profile of the water body was required at each location. Selected locations were identified to have stream velocity measurements taken and flow volumes calculated. Table 1 summarizes the stream locations, the estimated river feet/mile, the measured river feet/mile, and data collected.

During the field work the stream measurement team and the survey crew worked as a single unit at each of the study areas. This was decided to be the most advantageous approach because the study areas were in areas subjected to moderate to heavy public use. There was a concern that the public may pull out survey stakes or that the survey stakes left may present a risk to children playing in the vicinity. At the Brandywine Creek study area exposed stakes were removed after the survey effort was completed. In general, as the survey crew was running their "levels loop," the stream measurement team was placing stakes and taking stream measurements. Elevation stakes were placed at all cross-section point locations which were above water level. An additional stake was placed within the stream channel and the water elevation was recorded. Stream depth measurements were taken at 10-foot intervals. The stream depths values were subtracted from the water elevation to obtain stream channel elevations.

The cross-section locations along the Christina River were determined by hand measuring the distance from either the Smalleys Dam or the Smalleys Dam Bridge. The distances within the White Clay Creek and Brandywine Creek were shot using a Total Station System. All field work began after receiving a verbal "notice to proceed" from Stewart Lovell (DNREC).

Flow velocities were measured using a Swoffer Stream Velocity Flow Meter, Model #2100-1514. At study areas where the flow velocity was less than 1.5 ft/sec, the flow meter was field calibrated per manufacturer's recommendations.

The following is some additional study area-specific information recorded during the field investigation.

Christina River

On April 18, the Christina River study area was investigated. The flow meter was field calibrated to 135 pulses. The water elevations were recorded during the low tide period. Low tide was determined as directed by Gerald Kauffman (Reedy Point low tide period + 2 hrs, 18 minutes). Low tide for the 18th was determined to be at 11:22 AM. Water elevations were taken at CR#1 at 10:35 AM and at CR#2 at 11:46 AM.

White Clay Creek

On April 19, the White Clay Creek study area was investigated. The flow meter was field calibrated to 186 pulses. During the field reconnaissance DNREC requested that elevations at spacings of 20 feet and 40 feet outside the stream banks be recorded. During the investigation at this area, it was not always possible to achieve this request because of the presence of the canal. At WWC#1, the canal was located 24.5 feet from RB-4 (see Sheet 1 of 2). At WWC#2, the canal was located within 20 feet from RB-3 (see Sheet 1 of 2).

Brandywine Creek

On April 20, the Brandywine study area was investigated. The flow meter was field calibrated to 186 pulses. At BC#1, the canal was located 3 feet from LB-4 (see Sheet 2 of 2). A large boulder (approximately 16 feet wide) was located within the channel approximately 21 feet from LB-1. At BC#2, the canal was located 8.5 feet from LB-3 (see Sheet 2 of 2). At BC#3, the park parking lot was located 8.5 feet from RB-20 (see Sheet 2 of 2). At BC#4, a cemetery was within 20 feet of LB-3 and a park road was within 20 feet of RB-4.

As discussed during the field reconnaissance, BC#1 and BC#2 were relatively close. These locations were selected because of visible changes in stream velocities. BC#2 is believed to be representative of the steam profile for a significant distance downstream (300 to 400 feet). During the field investigation, it was noted that the canal overflow structure located between CR#2 and CR#3 had a noticeable effect on the nearby stream flow patterns. The discharged volume of water appeared to be causing a local hydrologic disruption in the flow, resulting in a pooling effect and a slight back current along portions of the channel edges. The area affected was located at approximately RM 2.84.

TABLE 1

STREAM LOCATIONS SUMMARY

LOCATION	ESTIMATED RF/RM	MEASURE RF/RM	CROSS-SECTION DETAILED	VELOCITY MEASUREMENTS TAKEN
WCC#1	57 + 800	57 + 970	✔	
WCC#2	57 + 000	57 + 030	✔	✔
WCC#3	56 + 000	56 + 623	✔	
WCC#4	55 + 000	55 + 713	✔	
CR#1	60 + 000	59 + 926	✔	✔
CR#2	59 + 400	59 + 207	✔	
BW#1	2.9	2.99	✔	
BW#2	2.7	2.95	✔	
BW#3	2.6	2.67	✔	
BW#4	2.5	5.55	✔	✔

MEMORANDUM

TO: Dave Yaeck, Bernie Dworsky June 21, 1995
FROM: Vic Singer
SUBJECT: Comments regarding .....

REPORT OF THE JOINT TASK FORCE INSTREAM FLOW NEEDS ANALYSIS FOR NORTHERN NEW CASTLE COUNTY, DELAWARE PHASE ONE: 7Q10 ASSESSMENT (Draft dated June 15, 1995)

During the June 20 Task Force Meeting and Public Briefing, the thought was expressed (not by me) that including written comments as an appendix to subject report would be considered. In that light, the following essay, prepared for a forthcoming issue of County Comments, the monthly newsletter of Civic League for New Castle County, is offered for your use.

A draft final report for Phase One of the Instream Flow Needs Analysis for Northern New Castle County has been completed and critiqued at a public comment session. Data generated by the analysis support conclusions that the report avoids making. No justification has yet been found for the DRBC Q7-10 rule-of-thumb minimum passby flow requirement for the Red and White Clay Creeks.

Hydrologic analyses at four target stream reaches have produced water depths and velocities for the Q7-10 flow level. The determined depths and velocities have been compared with critical habitat criteria for selected high-value species.

At the Stanton confluence of the Red and White Clay Creeks, the principal supply source for United Water Delaware (formerly Wilmington Suburban Water Corp), Q7-10 will diminish allowed withdrawals for fully ten weeks per year on the average.

In the freshwater portions of the Red and White Clay Creeks, which apparently include the region adjacent to the United Water Delaware plant at the confluence, the high value species designated by DNREC Fish and Wildlife are rainbow trout and brown trout. These require a one foot minimum water depth for spawning according to one of three cited authorities. (Lesser depths are sufficient according to the others.) The spawning seasons are February thru June for rainbow trout and September thru January for brown trout.

The analysis discloses that at the Q7-10 flow rate, the one foot minimum is not quite met under low tide conditions at only two isolated locations downstream of the water supply intake. Since the tidal range is substantial, the depth would seem to be more than the selected species need for spawning if short interruptions of their access to the full length of the stream are tolerable. Further, no justification is apparent for a Q7-10 minimum passby flow requirement in July and August, most of the period during which curtailments of withdrawals are contemplated.

Now come the rubs. DNREC Fish and Wildlife staff refuses to acknowledge that Q7-10 is an excessive minimum passby flow requirement without another year of study. Staff refuses to judge how large is the need for continuous access for spawning. Moreover, since neither of the selected species are native to these streams, they don't spawn there. The streams are stocked with these species.

If, as now required, the Q7-10 minimum passby flow requirement becomes fully effective in August 1996, water usage will have to be reduced. Since reducing fire protection is inconceivable, usage reductions will require industrial curtailments, and probable job losses and layoffs, all to assure conditions for spawning which won't occur anyway. Can we expect that the folks who become unemployed by curtailments that serve no demonstrated purpose will be happy for the opportunity to go fishing?

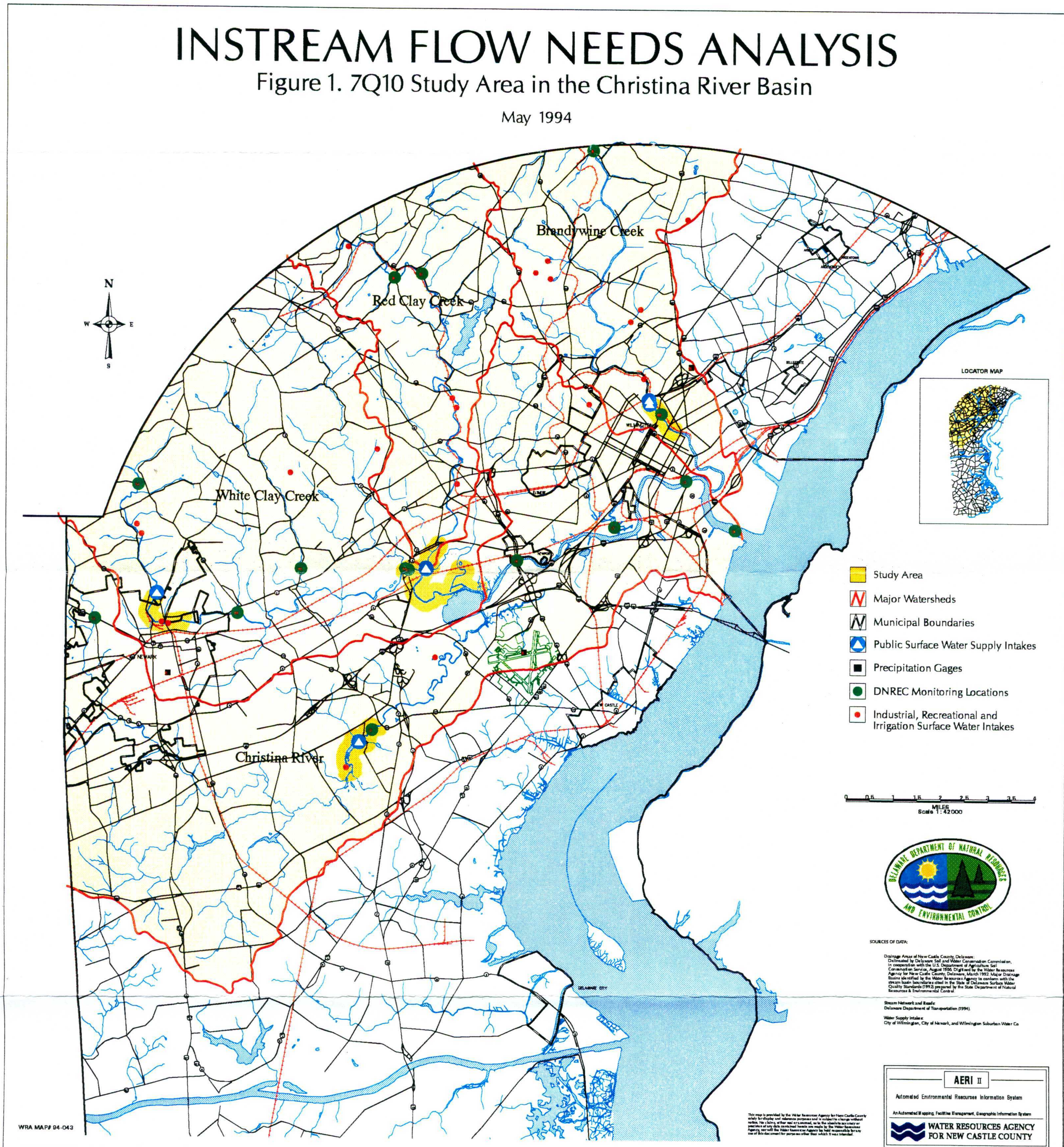

Figure 1. 7Q10 Study Area in the Christina River Basin

Figure 2. Study Reach along the Brandywine Creek at Wilmington

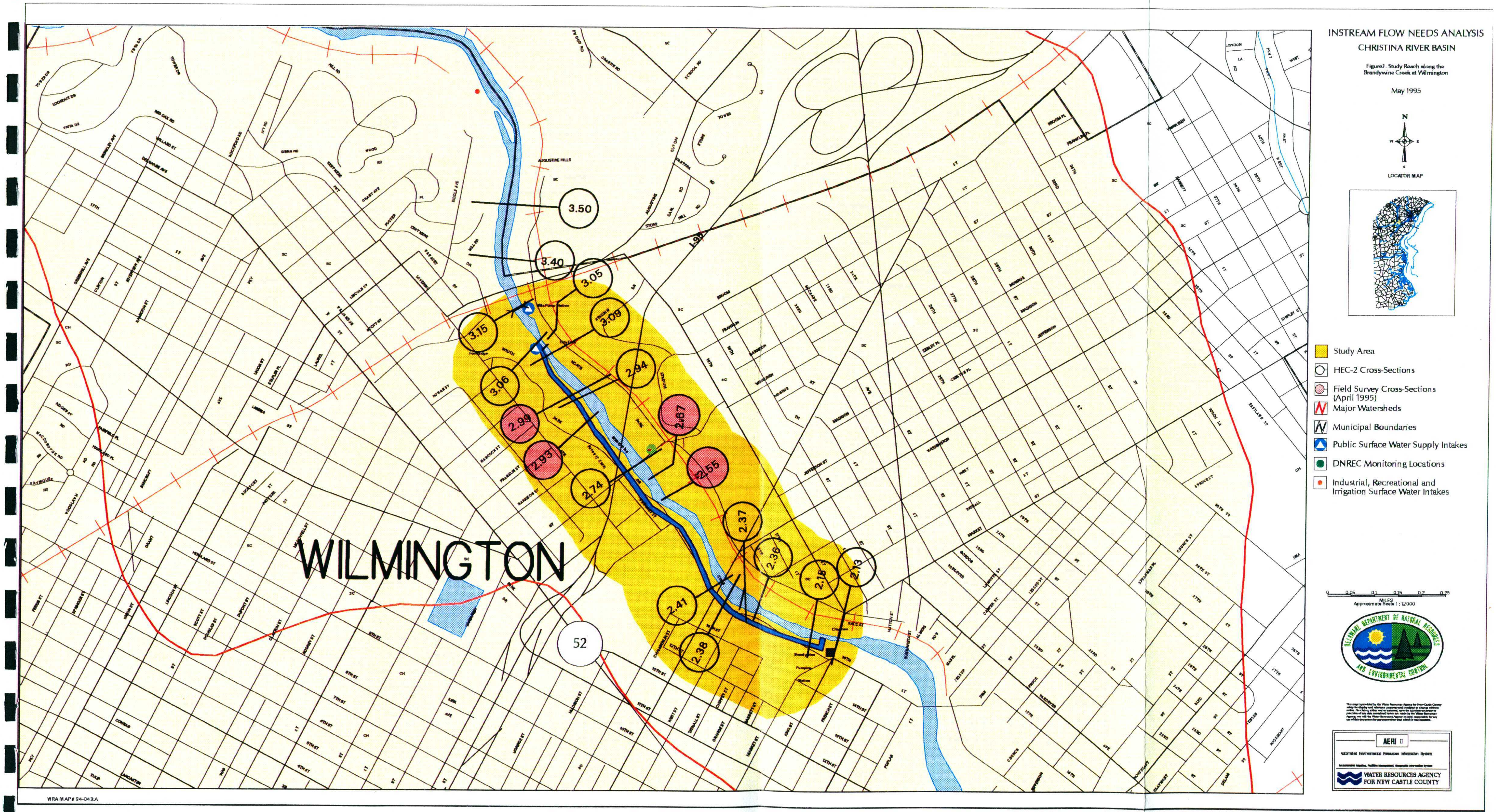

Figure 3. Study Reach along the Christina River at Smalley's Pond

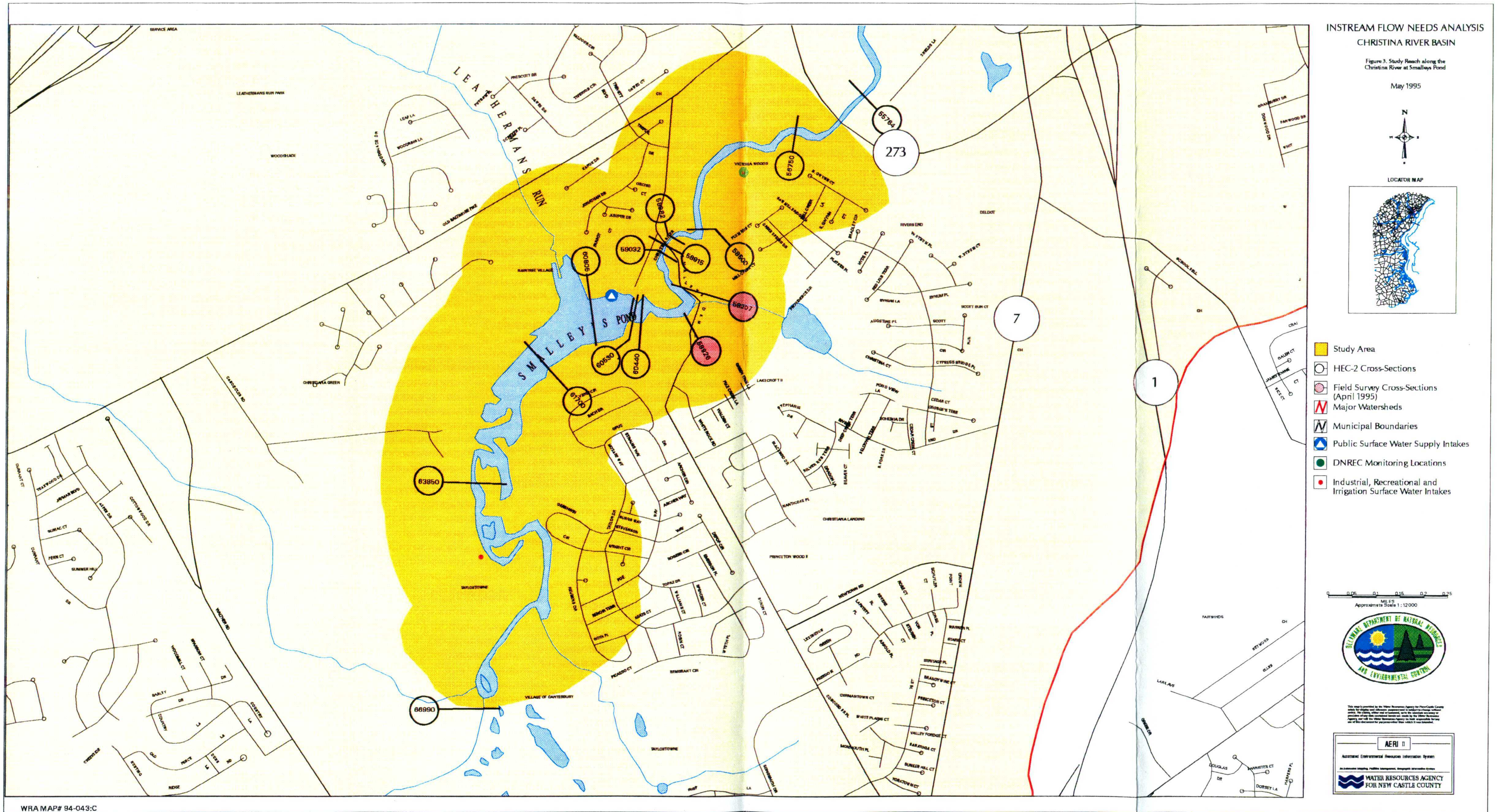

Figure 4. Study Reach along the White Clay Creek at Newark

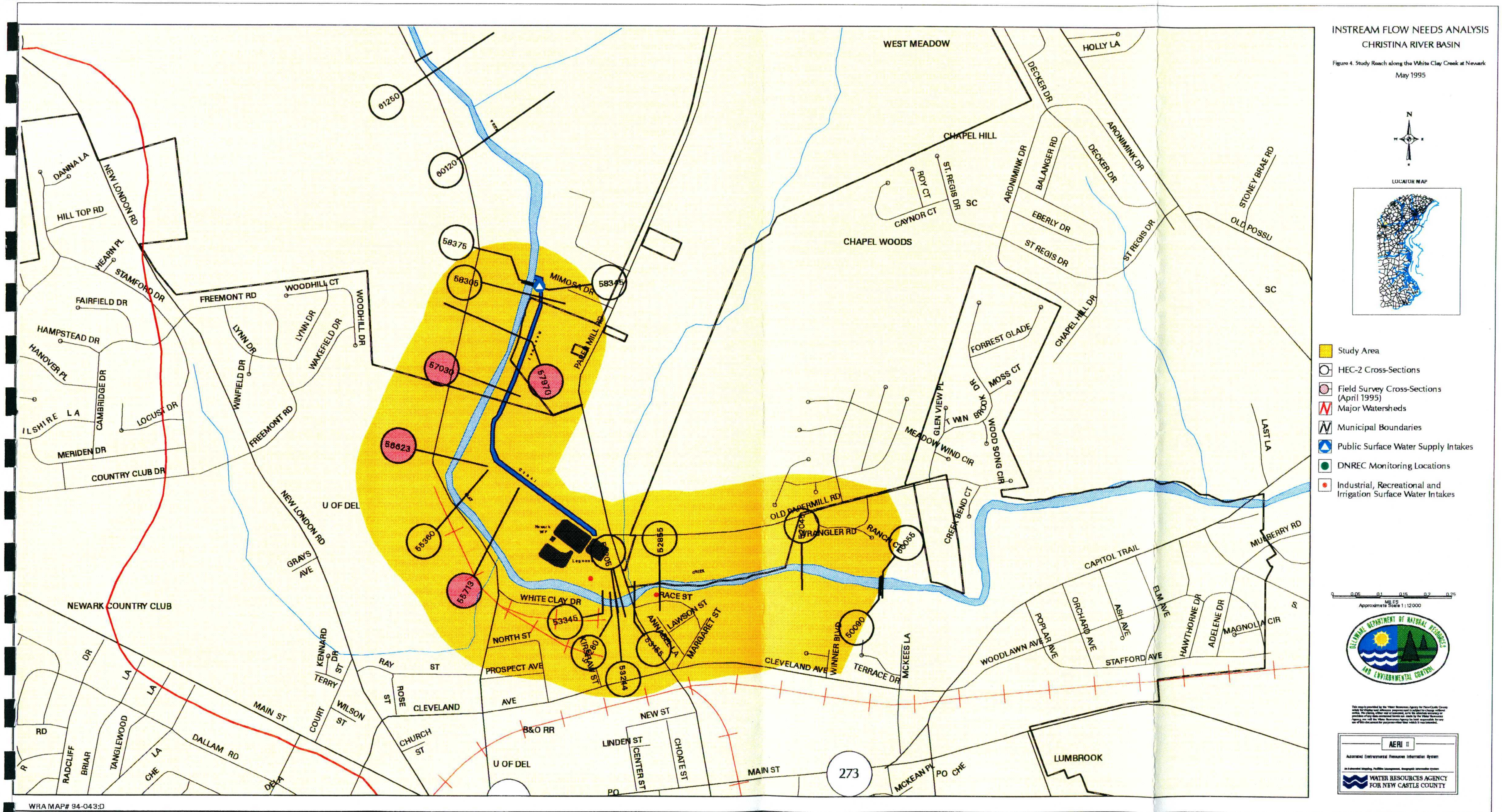

Figure 5. Study Reach along the White Clay Creek at Stanton