TECHNICAL MEMOS

PINELANDS COMMISSION

SURFACE WATER QUANTITY

BETZ * CONVERSE * MURDOCH * INC.

CONSULTING ENGINEERS, PLANNERS, AND COMPUTER SCIENTISTS

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SUMMARY OF PINELANOS SURFACE WATER HYDROLOGY

PINELANOS COMMISSION

FEBRUARY 1980

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SUMMARY OF PINELANDS SURFACE WATER HYDROLOGY

INTRODUCTION

Two of the principal objectives of the entire Pinelands program are to identify and assess the potential impacts of development on the Pine-lands natural systems and to develop recommendations to protect these systems. Towards these ends, an investigation into the hydrologic charccteristics of Pinelands surface waters was conducted.

Water is essential to the support of all elements of the physical and biological components of the Pinelands. The landscape was shaped by moving water, the forests require it for growth, fish and wildlife need it for habitat and growth and it is essential for all of the activities of man, including agriculture and urban development. Because of the importance of water to the maintenance of the Pinelands ecosystems, and because of the fragility of the water balance observed in developing and developed areas' outside the Pinelands, a considerable effort has been made to identify and assess the existing hydrologic relationships in the region. Much of this information was developed with the knowledge that understanding the existing water relationshfps was essential in order to determine the potential impacts of development on the Pinelands and' to establish sound recommendations for protecting the environment.

DESCRIPTION OF PROJECT TASKS

General

Eight major surface water hydrology tasks were addressed; they resulted' in an inventory and assessment of Pinelands surface water quantity and the development of recommendations for the management of the region:

1. Determine the hydrologic budgets of the Pinelands drainage basins (Technical Memorandum SW III-1)

2. Establish the flow characteristics (regime) of Pinelands streams and rivers (Technical Memorandum SW III-1)

3. Oescribe the relationship between groundwater and surface water (Technical Memorandum SW III-1)

4. Characterize the dynamic relationship between freshwater streamflow and estuarine salinity (Technical Memorandum SW III-1)

5. Determine the potential impacts of development on Pinelands hydrology (Technfcal Memorandum SW III-2)

6. Identify major issues related to surface water hydrology and recommend measures designed to mitigate the impacts of development (Technical Memorandum SW III-1)

7. Oevelop recommendations for future studies of Pfnelands surface water hydrology (Technical Memorandum SW III-1)

8. Obtain available flood plain maps, identify major issues related to flood plains, and recommend measures desfgned to mitfgate the impacts of development on flood plains (Technical Memorandum SW II)

Oetafled discussions of these tasks are contained fn the technical memorandums referenced in brackets after the task description.

Brief descrfptfons of task objectives, methods of analysis and findings are contained in the following sub-sectf ons.

<u>Oetermine the Hydrologic Budgets of the Pinelands Streams and Rivers</u>

<u>General</u>: The purpose of thfs task was to quantify the magnftude of the four major components of the hydrologic budget--average precipitation, evapotranspiration, streamflow, and inter-basin groundwater transfer--of each Pinelands drainage basin (Figure 1). Oata sources used for these mass balance analyses were an isohyet map of annual precipitation of the Pinelands and an isoevapotranspiration map of the Pinelands developed by Robertson and modified by BCM based on preliminary budget analyses and streamflcw records obtained from the U.S. Geological Survey. Interpolation and extrapolation were required for basins not containfng USGS ccntinuous recording streamflcw gaging stations, or with records spanning only several years or less.

BCM

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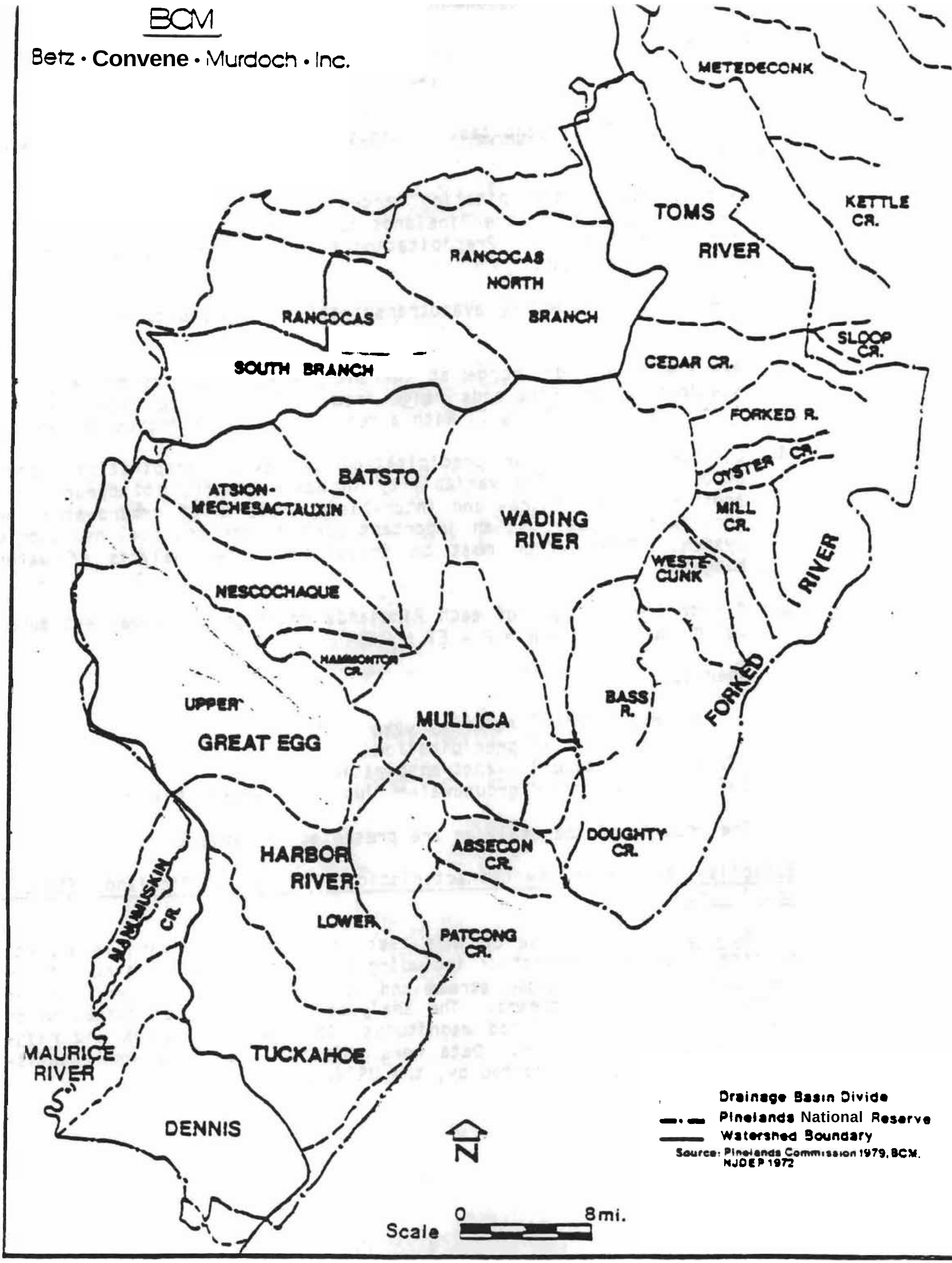

Figure 1. PINELANDS DRAINAGE BASINS

Findinas: Signficant task findings are summarized in the following paragrapns.

I. Average annual precipitation ranges from about 44 inches near the western boundary of the Pinelands to about 46 inches in the central portion of the area. Precipftation along the coast is approximately 33 inches per year.

2. Average annual actual evapotrenspiration ranges between 20 and 23 inches.

3. Average annual discharge at currently operating streamflow gaging stations in the Pinelands range from 13.6 inches per year to 51.4 inches per year (Table I) with a mean flow of 23.5 inches per year.

4. Because variations in precipitation and evapotranspiration cannot account for the wide variability in basin runoff, it appears that another factor, intra- and inter-basin transfer of groundwater (or groundwater flux), is an important part of the, regional hydrologic system. This factor must be included in the analysis of water budgets.

5. A hydrologic budget of each Pinelands drainage basin was estimated using the equation R = P - ET ± GWF

where:

2 = average annual runoff
P = average annual precipitation
ET = average annual evapotranspiration
GWF = average annual groundwater flux (intet-basin transfer)

The results of the analyses are presented in Table 2.

Establish the Streamflow Characteristics (Regime) of Pinelands Streams and Rivers

General: The purpose of this task was to quantify varicus aspects of streamflow characteristics including daily, monthly, and annual fluctuations within each gaged stream and to identify the' similarities and differencas between streams. The analyses included a determination of flow duration curves, flood magnitudes, low flow magnitudes and rainfall-runoff relationships. Oata were obtained from, and some statistical analyses were conducted by, the USGS.

TABLE I

AVERAGE ANNUAL FLOW RATES AT U.S. GEOLOGICAL SURVEY STREAMFLOW GAGING STATIONS

Gaging Station Identification Number	Stream Name and Location	Drainage Basin	Period of Record (Water Years)	Drainage Area (mi^2)	Average Discharge Per Square Mile (cfs/mi^2)	Average Discharge (inches/year)
01408500	Toms River near Toms River	Toms River	1929-78	124.0	1.73	23.5
01409000	Cedar Creek near Lakoda	Cedar Creek	1933-58, 1971	56.0	1.91	25.9
01409095	Oyster Creek near Brookville	Forked River	1966-78	7.43	3.80	51.4
01409280	Westecunk Creek at Stafford Forge	Forked River	1974-78	16.0	1.96	26.7
01409400	Mullica River near Batsto	Atsion-Mechesactauxin	1958-78	64.4	1.74	23.6
01495000	Batsto River at Batsto	Batsto	1927-78	70.5	1.79	24.3
01409810	West Branch Wading River near Jenkins	Wading River	1975-78	84.1	1.18	24.1
01410000	Oswego River at Harrisville	Wading River	1931-1978	64.0	1.38	18.1
01410500	Absecon Creek at Absecon	Absecon Creek	1924-28,33-38,47-78	16.6	1.62	22.0
01410787	Great Egg Harbor River Tributary at Sicklersville	Upper Great Egg Harbor River (GEHR)	1973-78	1.64	1.06	14.4
01408100	Four Mile Branch at New Brooklyn NJ	Upper GEHR	1973-78	7.74	1.48	20.1
01410600	Great Egg Harbor River near Blue Anchor	Upper GEHR	1973-78	37.3	1.52	20.6
01411000	Great Egg Harbor River at Folsom	Upper GEHR	1925-78	56.3	1.54	20.93
01411300	Tuckahoe River at Head of River	Tuckahoe River	1971-78	30.8	1.33	18.1
01465850	South Branch Rancocas Creek at Vincintown	South Branch Rancocas Creek	1962-75	64.5	1.46	19.7
01466000	Mt. Misery Brook in Lebanon State Forest	North Branch Rancocas Creek	1952-65	2.71	0.71	9.64
01466500	McDonalds Branch in Lebanon State Forest	North Branch Rancocas Creek	1965-78	2.37	1.00	13.6
01467000	North Branch Rancocas Creek at Pemberton	North Branch Rancocas Creek	1921-78	111.0	1.54	20.9
01411500	Maurice River at Norma	Maurice River	1932-78	113.0	1.49	20.2
01412000	Manantico Creek near Millville	Manantico River	• 1932-57, 1971	22.3	1.69	22.9

• Average Discharge Other Periods column data were developed in order to review the reliability of mean flow data for gaging stations with short periods of record. Uses of these data are listed in the footnotes of this table.

TABLE 2

BUDGET ANALYSIS DATA

Basins	Precipitation (Inches)	Evapotranspiration (Inches)	Calculated Runoff (Inches)	Runoff (Inches)a Measured	Adjusted	Estimated	Difference** (Inches)	Difference Vol. in-mi²
Toms River	45.6	22.3	23.5	23.5	---	---	0.0	---
Rancocas River Basin	44.7	22.6	22.1	---	---	---	---	---
North Branch Rancocas	45.0	22.6	22.4	20.9	---	---	- 1.5	-166.5
South Branch Rancocas	44.1	22.5	21.6	19.7	---	---	- 1.9	-122.6
Cedar Creek	44.4	21.4	23.0	25.9	---	---	2.9	+162.4
Forked River Basin	43.8	20.5	23.3	---	---	---	---	---
Forked River	43.9	20.8	23.1	---	---	25.9	+ 2.8	+ 43.1
Oyster Creek	43.6	20.6	23.0	51.4***	41.0	---	+18.0	+207.0
Mill Creek	42.7	20.4	22.3	---	---	27.2	+ 4.9	+100.0
Westecunk Creek	43.9	20.5	23.4	26.7	---	---	+ 3.3	+ 52.8
Mullica River Basin	44.7	21.6	23.1	---	---	---	---	---
Bass River	43.5	20.6	22.9	---	---	22.9	0.0	---
Wading River	45.7	21.6	24.1	21.8	---	---	- 2.3	---
West branch Wading River	45.7	21.6	24.1	24.1	---	---	0.0	---
Oswego Creek	44.8	21.4	24.4	18.7	---	---	- 5.7	-364.8
Batsto River	44.6	21.6	22.9	24.3	---	---	+ 1.4	+ 98.7
Atsion-Mechesactauxin Creek	44.2	21.9	22.3	23.6	---	---	+ 1.3	+115.4
Nescochaque Creek	44.4	22.1	22.3	---	---	22.3	0.0	---
Hammonton Creek	44.8	21.8	23.0	---	---	23.0	0.0	---
Mullica River	44.1	21.0	23.1	---	---	23.1	0.0	---
Great Egg Harbor Basin	44.4	22.0	22.4	---	---	---	---	---
Upper Great Egg Harbor	44.6	22.4	22.2	20.9	---	---	- 1.3	-221
Lower Great Egg Harbor	44.7	21.4	23.3	---	---	23.3	0.0	---
Maurice River Basin	42.8	22.8	20.0	---	---	---	---	---
Manumuskin Creek	43.0	22.8	20.2	---	---	20.2	0.0	---
Maurice River	42.5	23.0	19.5	20.2***	19.5	---	0.0	---
Absecon River	43.0	20.7	22.3	22.0***	22.3	---	0.0	---
Tuckahoe River	44.3	21.9	22.4	18.1	---	---	- 4.3	---
Dennis Creek	42.4	22.5	19.9	---	---	19.9	0.0	---
Patcong Creek	41.3	20.8	20.6	---	---	20.5	0.0	---

a Use the runoff value furthest to the right for budget computation.

** Attributable to basin transfer except at Tuckahoe River.

*** Gage significantly upstream of basin outlet - flow adjusted to represent entire basin.

Findings: Significant findings on streamflow characteristics are described in the following paragraphs.

1. Mean annual discharge may vary considerably from year to year. For example, for the period 1930-1978, mean annual streamflow of the Batsto River at Batsto has ranged from 193 cubic feet per second (cfs) to 66 cfs.

2. Streamflow varies on a seasonal basis. Although precipitation is highest during July and August, streamflow tends to be hfghest during March and lowest during September and October.

3. Flow duration curves developed for each set of streamflow gaging records indicat d that streamflow is relatively uniform in several streams. For example, ratios of the discharges exceeded 10% and 90% of the time for the Toms River, Cedar Creek, Oyster Creek, Westecunk Creek, Batsto River, Fourmile Branch, Great Egg Harbor River (at Folsom) and McDonalds Branch were all less than 4.0. The stations with the greatest variability of flaw were Absecon Creek (14.4) and Great Egg Harbor Tributary at Sicklersville (12.6). The variability of these two streams are the result of withdrawals for water supply (Absecon Creek) and urban runoff (GEHR Tributary at Sicklersville).

4. Low flows on headwaters streams (represented by McDonalds Branch) are higher on a unit area basis than for the larger basins.

5. Peak flood flow rates are low on Pinelands streams. Peak flow rates for the 10-year flood range from 9.7 cfs/sq.mi. for McDonalds Branch to 26.2 cfs/sq.mi. for Oyster Creek.

6. Flow frequency analyses of each gaging staticn with a sufficiently long record was conducted for the 1-, 3-, 7-, 14-, 30-, 60-, 90-, 120- 183- and 365-day low flows for return fntervals ranging from I to 200 years. Results of the analyses are presented in Table 8 and Appendix 1 of Technical Memorandum SW III-1.

7. Direct runoff (channel precipitation, surface runoff and rapid interflow) averages approximately 2.5 Inches per year, which is approximately 11% of the total annual runoff and about 6% of the mean annual precipitation.

8. The relationship between rainfall and direct runoff is not uniform. For three small basins analyzed in detail, direct runoff from a four-inch storm ranged between 2.1 and 6.5 percent of rainfall.

3. The percentage of direct runoff depends largely on the amount of "effective" area in a watershed. Analyses showed that the "effective" area of a watershed could be reasanably estimated using the hydrologic soil group concept developed by the Soil Conservation Service. Percentage of "0" and "C" hydrologic soils groups, those groups described as having high and very high runoff rates and low infiltraton rates were measured for three gaged undeveloped watersheds. Higher percentages of those soils were correlated with higher volumes of dfrect runoff.

10. Runoff volumes predfcted using SCS's Soil Cover Complex Method were compared with those developed by rainfall-runoff analysis for two basins. The results differed between the two streams.

11. Because their contrfbution of direct runoff is less, those portions of a basin with relatively low percentages of effective area contribute higher unit flows during periods with little or no precipitation.

Describe the Relationship between Groundwater and Surface Water

General: Two principal aspects of this relatfonshfp were looked at: the influence of water table fluctuation on streamflow and major intra- and inter-basin transfers of groundwater and their effects on streamflow. Streamflow and water table information was obtained from USGS records. Transfers of water were based both on streamflow records and assessments of drainage basin characterfstics performed by the project stcff.

Findinas: Four important findings are presenttd in the following paragraphs.

1. Groundwater discharge is responsible for approximately 89% of streamflow and all or nearly all streamflow during periods of drought.

2. Water table elevations and streamflow both vary seasonally. They normally peak during March and are lowest in September and October.

3. A comparison between dafly streamflow and water table elevations fcr McDonalds Branch and a nearby well indicate that water table and streamflow fluctuations are related and that water table elevation is a good indicator of streamflow, especially during median and low flow periods.

4. Groundwatsr is transferred on both an intra-basin and inter-basin basis. This accounts for the considerable range of average mean annual streamflows previously noted. Based on information from the continuous recording gages in the North Branch Rancocas Creek Basin, it appears that some of the water infiltrated near the basin divides bypasses the local groundwater discharge system and is discharged into downstream portions of the drainage basin. Inter-basin transfer of groundwater Is evidenced by streamflow data for three contiguous basins in the northeast portion of the Pinelands. Oswego Creek (drainage area = 64 sq.mi.; average annual discharge = 18.7 inches) drains in a southwesterly direction while the adjacent Oyster Creek (drainage area = 7.43 sq. mi., average annual discharge = 51.4 inches) and Westecunk Creek (drainage area = 16.0 sq.mi., average annual runoff = 26.7 inches) drain more steeply to the coastal bays. A hypothesis is made that the groundwater divide between Oswego Creek and the other basins lies westward of the topographic divide.

Characterize the Dynamic Relationship between Freshwater Streamflow and Estuarine Salinity

General: The goal of this task was to attempt to establish minimum streamflows necessary to maintain satisfactory salinity levels in area estuaries. The principal source of information was the report by Durand and Nadeau on the Mullica River Estuary. An evaluation of available information during the current study resulted in the conclusion that minimum flows could not be determined using the current base of data. Instead, monthly flon and flows of various exceedances probabilities were developed for each drainage basin as a guide, but not as a recommendation, for possible minimum low flows.

Findings: Six findings are presented in the following paragraphs.

1. Considerable information on estuarine salinity is available for the Mullica River estuary. Much less data are available for other Pinelands estuaries.

2. Salinity at any point in an estuary is a function of the quantity of freshwater streamflow entering the estuary, tidal stage and fluctuations, distance from the estuary's upstream terminus and the shape of the estuary.

3. Salinity can vary sharply at a particular station. For example, salinity at one point in the Mullica River estuary dropped from 17 parts per thousand (ppt) to 4 ppt in a three-day period as a result of a large increase in streamflow into the estuary.

4. Estuarine salinity levels vary considerably frcm month to month and year to year, with streamflow fluctuations being the major contributing factor.

5. The monthly Batsto Rfver streamflows recommended by Durand and Nadeau for the maintenance of recommended monthly salinity values were evaluated. No consistent relationship was found between the flows and the lfkelihood that the particular flow could be obtained fn any given year. For example, it was determined by statistical analysis of streamflow records that the recommended minimum average streamflow for October has a 47% chance of not being obtained in any given year, while the streamflow for August only has a 22% chance of not being obtafned. As a result, recommended minimum flows for the streams entering the Mullica River estuary could not be developed. Nor were there any relationships developed for the Mullica River whfch could be extrapolated to other freshwater-estuarine systems.

6. In lieu of recommending streamflows, monthly flows for each of the Pinelands drainage basins whfch have a 75, 90 and 98% probability of being equaled or exceeded in any given year, together wfth the likelihood of exceedance from Durand and Nadeau's recommendations for the Mullica River estuary were developed for guidance only.

<u>Determine the Potential Impacts of Development on Pfnelands Hydrology</u>

<u>General</u>: The purpose of this element was to evaluate the impacts of development on the rainfall-runoff relationship, especially with regard to increases in the peak rates and volumes of stormwater runoff, and the consequent impacts on groundwater recharge, Computer models of four small Plnelands watersheds were used to demanstrate the potential impact of development in the Plnelands on stormwater runoff. Also, information from Long Island, New York, an area that shares many hydrologic similarities with the Pinelands, was used to predict the impacts from development.

<u>Findings</u>: The findfngs of this task are presented fn the following paragraphs.

1. Long Island, New York, an area wfth many hydrologic conditions similar to the Pinelands, was used to document the impacts of urban development an dfrect runoff. An analysis of one watershed indicated that urbanization resulted in a 170% increase in annual dfrect runoff. Peak rates of runoff for one storm increased by 150 percent. Direct runoff from individual storms were 1.1 to 4.6 times greater than the correspondfng runoff prior to development. Annual direct runoff from storm-sewered areas was 9.4 times the average annual amount prior to development.

2. A comparison of the volume of direct runoff for the Great Egg Harbor River Tributary at Sicklersville, a partially urbanized basin, with data for other Pinelands streamflow stations, indicates that residential development has increased the volume of direct runoff resulting from rainfall events.

3. The SCS's TR-20 computer program, with two modifications and proper estimates of basin characteristics, was used satisfactorily to simulate direct runoff from a small gaged Pinelands drainage basin (McDonalds Branch).

4. An analysis of hypothetical development scenarios (see Table 3) on four small ungaged Pinelands drainage basins indicated that without proper stormwater management, peak flood flow rates will increase significantly (Table 4). For example, analysis of one watershed, Biddle Branch, a tributary of the West Branch Wading River, indicated that single-family residential development on one-acre lots served by storm sewers will increase peak discharge and volume of direct runoff of the 10-year flood by 4.6 times and 4.9 times, respectively.

5. Increased rates of direct runoff will result in less aquifer recharge and lower base and low streamflows.

6. In-stream stormwater detention ponds, such as the one located on the Great Egg Harbor Tributary at Sicklersville, are not likely to maintain existing direct runoff relationships. Therefore, this type of stormwater management device should not be recommended where recharge to the groundwater reservoir and maintenance of existing base and low streamflow are required.

7. Stream channel "improvements," such as straightening, widening and vegetation removal, which may accompany development, can have a significant impact on flood flow rates. A computer analysis indicated that, by reducing natural channel and flood plain retardence, peak flood flow rates increased by 67 percent.

8. Annual and low streamflow will be reduced if domestic water supply is drawn from shallow local wells (within the immediate drainage basin) and exported downstream by sanitary sewers for treatment. Assuming a development density of one home per acre, the annual streamflow in a small tributary similar to McDonalds Branch could be reduced by as much as 35 percent.

Each of the major findings presented previously, and the means by which they were developed, are explained in detail in Technical Memorandums SW III-1 and SW III-2.

TABLE 3

LAND DEVELOPMENT SCENARIOS

Scenario Number	Land Use Description*	Drainage Basin Biddle Branch	Cooks Branch	Pole Bridge Branch	Clarks Branch
1	Existing land use	X	X	X	X
2	Pre-agricultural land use				X
3	Residential development (1 home/acre); complete storm sewering	X	X	X	X
4	Cluster residential (3 homes/acre, 1-acre gross density); no storm sewers	X	X	X	X
5	Multiple land uses:				
	Residential single-family (4 homes/acre) 17% Residential multi-family 17% Commercial 17% Light Industrial 17% Open Space 32%	X	X	X	

* Development in scenarios 3, 4 and 5 was excluded from areas of permanantly high water table (D soils). Percentages of the hydrologic soil groups in each basin development are found in Table 3.

TABLE 4

RESULTS OF THE DRAINAGE BASIN SCENARIO ANALYSIS FOR THE 10-YEAR FLOOD

Drainage Basin	Scenario Number	Peak Discharge (cfs)	Ratio of Discharge to Discharge for Existing Locations	Total Runoff from Drainage Area (Inches)	Ratio of Basin Runoff to Basin Runoff for Existing Conditions
Biddle Branch	1	37.9	---	0.33	---
	3	172	4.6	1.6	4.9
	4	47.7	1.3	0.49	1.5
	5	228	6.0	2.1	6.4
Clarks Branch	1	123	---	1.0	---
	2	47.6	0.4	0.90	0.5
	3	178	1.5	2.7	1.5
	4	132	1.1	2.1	1.2
Cooks Branch	1	63.2	---	0.39	---
	3	299	4.7	1.9	5.0
	4	118	1.9	0.82	2.1
	5	390	6.2	2.3	6.0
Pole Bridge Branch	1	97.8	---	0.78	---
	3	313	3.2	2.6	3.4
	4	217	2.2	1.9	2.4
	5	371	3.8	3.1	3.9

Source: BCH

Identify Major Issues Related to Hydrology and Recommend Measures Designed to Mitigate the Impacts of Development

Based on the inventcry and analysis of the hydrologic characttristics of the Pinelands established in Technical Memorandum SW III-1 and the potential impacts of development established in Technical Memorandum SW III-2, several major findings were noted. Relationships between these issues became apparent; they are discussed in the Major Conclusions section of this technical memorandum. For example, the protection of prime groundwater recharge areas is critical. This conclusion is based on the high percentage of precipitatfon which infiltrates through the soil to the groundwater. reservoir, the base flows sustained by ground-water runoff, the apparent source areas of recharge and runoff, and the observation of significant intraand inter-basin transfers of ground-water, Several measures designed to maintain the hydrologic relationships fn the Pinelands were discussed in Technfcal Memorandum SW III-2. Others are described fn a latter section of this technical memorandum.

Develop Recommendations for Future Studfes of Pinelands Hydrology

At the outset of the current study, it was clear that much of the information needed to develop a complete understanding of Pinelands hydrology was unavailable. Several information gaps have been identffied during the current study, Additionally, several analyses which were beyond the present scope of services would be valuable for establishing a better understanding of the hydrology of the Pinelands. Suggestions for future study are listed in this report.

Obtain Available Flood Plain Maps, Identify Major Issues Related to Flood Plains, and Recommend Measures to Mitigate the Impacts of Development on Flood Plains

General: Flood hazard area maps have been prepared or are being prepared for 49 of the 52 Pinelands municipalities by the Federal Emergency Management Agency (FEMA). For a municipality to participate in the federal flood insurance program and thereby aualify local property owners for federally subsidized flood insurance, each municipality is required to adopt flood plain management regulations.

Findings: Significant task findings are summarized in the following paragraphs.

1. FEMA community maps were prepared by using "approximate" methods. These maps do not contain ftood elevations, do not always show the extent of flood plains on all streams, and are difficult to us2 because they generally have few geographic references.

2. Regulations included in most local flood plain management ordinances are sufficient to regulate development.

3. Channel straightening and eliminating natural flood plain vegetation (except for the purpose of cultivating cranberries) will increase peak flood flow rates. Dikes constructed for cranberry propagation act similarly to natural vegetation in slowing flood runoff.

CONCLUSIONS

Based on the individual findings listed in the previous section, the following four major conclusions regardfng the hydrology of the Pinelands surface water system have been developed:

1. Most major flow characteristics of Pinelands streams are functions of the runoff and infiltration characteristics of a drainage basin's soils.

2. Intra-basfn and fnter-basin transfers of groundwater are related to major regional source areas of infiltration, thickness of the unsaturated zone and basin ground slope.

3. Poorly managed urban development will upset the existing streamflow characteristics of Pinelands drainage basins and streams.

4. Large areas of the Pinelands are subject to periodic flooding.

Discussions of these conclusions are presented in the paragraphs which follow.

<u>*Most* Major Streamflow Characteristics of Pinelands Streams are Functions of the Infiltration and Runoff Characteristics of Drainage Basin Soils</u>

With the exception of variations resulting from fluctuations in precipitation, most major flow characteristfcs of Pinelands streams (including percentages of direct and base runoff, low flows, and peak flood flows) are functions of the infiltration and runoff characteristics of drainage basin sofls. Approximately 11% of the annual runoff in the Pinelands is direct runoff from precipitation. The percentage of direct runoff from individual storms was shown to vary based on the percentage of a drainage basin underlain by "effective" source areas for airect runoff; the higher the percentage of effective' area, the higher the percentage of direct runoff. Annual direct runoff appears to vary on a similar basis. A corollary to this relationship is that the greater the percentage of a basin which is not a source area for direct runoff, the higher the percentage of storm rainfall which enters the soil and may percolate to the water table. As a result, those basins with high percentages of noneffective area should contribute a higher unit discharge to local streamflow during low flow periods than those basins, or portions of basins, with lesser infiltration capacity and groundwater recharge.

The Soil Conservation Service's hydrologic soil group classifications C and D were shown in Technical Memorandum SW III-1 to be a reasonable indicator of effective areas for direct runoff. A and B hydrologic groups soils, especially the A soils, are therefore areas of highest infiltration and groundwater recharge. McDonalds Branch, which has a very high percentage of A soils (77.5%) and low percentage of C and D soils (10.8%), is representative of the type of watershed with relatively low percentages of direct runoff and high unit rates of low flow.

Based on the relationship between hydrologic soil groups and direct runoff, areas of A soils and B soils surrounded by A soils are probably the most significant areas of recharge to the groundwater reservoir. These areas can easily be delineated on the soils maps prepared for the Commission by another contractor.

<u>Intra-basin and Inter-basin Transfers of Groundwater are Related to Major Regional Areas of High Infiltration and Thickness of the Unsaturated Zone and Basin Ground Slope</u>

Major differences in average mean annual discharge have been observed in the Pinelands streamflow data. Oyster Creek, a smaller watershed draining relatively steeply toward Barnegat Bay, has an average mean annual flow 2.8 times the flow of neighboring Oswego Creek, a larger, more gently sloping basin draining toward the Mullica River estuary. The mean flow for Oyster Creek actually exceeds average basin precipitation. A second example is the North Branch Rancocas Creek drainage basin, where the gage at Pemberton has recorded an average mean discharge of 20.9 inches per year, while upstream at McDonalds Branch, annual flow averages only 13.6 inches. Because rainfall is fairly uniform over the area, and because stream gage error has been ruled out, it is apparent that water is infiltrating to the groundwater reservoir, bypassing the nearby stream and discharging either further downstream or into a stream in a different watershed. In the case of intra-basin transfer, it is likely that the principal sources of recharge, the A, and some areas of B soils, are infiltrating water which not only sustains local base flow, but also has a positive effect of increasing downstream low flows. In the case of inter-basin transfer, these same type areas are contributing toward the groundwater discharge in adjacent drainage basins.

At the present time, the dynamics of the transfer system and the source areas are not well understood. The best estimate of the extent of source areas for intra- and inter-basin transfers are portions of the Pinelands where the thickness of the unsaturated zone is greater than 10 feet. These areas are at or near topographic drainage divides where the opportunity for deep infiltration and groundwater movement is higher.

<u>Poorly Managed Urban Development will Upset the Existing Streamflow Characteristics</u>

An analysis of information from other areas, together with analyses of the potential hydrologic impacts of development in the Pinelands, documents the type and magnitudes of hydrologic changes which might occur in the Pinelands from urban development. These impacts include up to a six-fold increase in peak flood flow rates, increased percentage of direct runoff and resultant decreases in groundwater recharge, and stream channel erosion and enlargement.

The impervious surfaces of newly urbanized areas (or areas of C and D soils), if connected directly or by a natural swale or storm sewer to stream channels, act to increase the percentage of "effective" area in a watershed, resulting in greater runoff volumes. Water moves rapidly over the man-made surfaces, which increases the peak rate of flow. Stormwater detention facilities reduce the peak flow rates but not the volume of runoff from newly constructed impervious buildings, parking lots, etc. Also, if water supply is withdrawn by local wells in a headwaters area similar to the McDonalds Branch basin and exported to lower areas of the watershed via sanitary sewers after use, local streamflow may be reduced by as much as 35 percent.

<u>Large Areas of the Pinelands are Subject to Periodic Flooding</u>

Those lowland areas subject to periodic flooding can best be identified by mapping the alluvial soils and muck. This has been done by another contractor. Development in these areas is subject to flood damage and may endanger human safety. Flood plains also serve many functions critical to Pinelands ecology; development on flood plains will disrupt these functions.

MAJOR ISSUES AND RECOMMENDATIONS

Major Issues

Three major issues emerge from the analyses of the surface water quantity characteristics of the Pinelands National Reserve:

1. How should prime groundwater recharge areas* be protected in order to ensure the maintenance of the present flow regimes of Pinelands streams within, and downstream from, the Pinelands National Reserve?
2. How should urban development be accommodated without altering the hydrologic relationships within the drainage basins of the Pinelands National Reserve?
3. How should flood plain areas be managed?

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* A prime recharge area is an area underlain by soils having moderately high to excessively high infiltration capacity. Prime recharge areas are identified as follows:

  - All areas of A hydrologic group soils
  - All areas of B hydrologic group soils that are surrounded by A soils
  - All areas where the thickness of the unsaturated zone is greater than 10 feet

  These areas can be readily identified on the 1:24,000-scale soils maps in the possession of the Commission and on the thickness delineation on the unsaturated zone map prepared by the groundwater subcontractor. A list of the Pinelands area soil series within A and B hydrologic soil group categories is contained in Table 5.

  Approximately 32% of the Pinelands region is composed of A soils. No estimate is available of the amount of B soils located wholly within areas of A soils.

TABLE 5

HYDROLOGIC SOILS GROUPS OF MAJOR PINELANDS SOIL SERIES

Soil Series	Hydrologic Soil Group*	Percent of Pinelands**
Lakewood	A	12
Evesboro	A	9
Fort Mott	A	< 1
Lakehurst	A	11
Total Percent of "A" Soils		32
Woodmansie	B	4
Downer	B	17
Sassafras	B	3
Aura	B	5
Klej	B	3
Total Percent of "B" Soils		32
Hammonton	C	4
Woodstown	C	< 0.5
Atsion	C	12
Marlton	C	< 0.5
Total Percent of "C" Soils		17
Fallsington	D	< 0.5
Berryland	D	4
Pocomoke	D	2
Muck	D	10
Alluvial land	D	--
Total Percent of "D" Soils		16

Source:

* USDA, SCS National Engineering Handbook, Vol. 4, Hydrology, 1972

** Marco L. Markley, Soil Series of the Pine Barrens; Pine Barrens Ecosystem and Landscape, 1979

Each issue has within it several sub-issues. The sub-issues can be generally categorfzed in terms of what, where, and how. These issues, or questions, are addressed below.

Recommendations

1. How can prime groundwater recharge areas be protected?

   The two princfpal options available are:

   a. Prohibit development on these areas

   b. Allow certain types of development on these soils and require strfngent performance standards

   Prohibiting development would be the fdeal approach to protecting recharge areas. This might be accomplished by purchasing the land, zoning the land as open space, or encouraging cluster development in adjacent areas. However, lfmited development, using strict performance standards, would be suitable.. The princfpal performance standard would be the mandatory requirement far stormwater devices designed to allow on-site infiltration of precipitation (see Table 6 for descriptions of infiltration management alternative controls).

   These areas, in addition to being most important for groundwater recharge, are highly sensitfve to contamination from point and non-point sources of pollution. Therefore, ft is recommended that potential sources of significant contamination be prohibited from these areas (set Technical Memorandum SW IV-1 for additional information on the impacts of development on water quality).

2. How can urban development be accommodated without altering the area's hydrologic characteristics?

   a. Where can urban development take place?

      High density development should be limited to areas which will have the least impact on Pinelands hydrology (non-prime recharge areas). Low intensity residential development can be accommodated solely from a water quantfty point of view, in prime recharge areas, provided suitable stormwater on-site infiltration management techniques are applied and untreated wastewater is not exported from the area.

b. What stormwater management techniques are recommended?

Alternative stormwater management techniques are described in Table 6. Management techniques for all development should include methods for on-site infiltration of stormwater in order to maintain the existing peak rates of runoff and the existing volume of direct runoff. Retention, without infiltration, should only be allowed where a special exception can be justified by an applicant.

c. What volume of water should be required to be retained for purposes of infiltration?

The 10-year, 24-hour storm (5.3 inches) should be the minimum design storm for stormwater and infiltration management. Rainfall in excess cf this amount should be allowed to drain into naturally vegetated swales.

d. What runoff calculation methodology is acceptable?

The Soil Conservation Service's Soil Cover Complex Method is recommended as the sole acceptable method. The analyses contained in Technical Memorandum SW III-2 demonstrates that, with a few adjustments, use of this method can produce reasonably accurate results. The computer version of the method allows for a more thorough analysis than other methods, such as the Rational Formula.

3. How should the 100-year flood plain areas be managed?

The regulations contained in the flood management ordinances of the municipalities participating in the National Flood Insurance Program are satisfactory for managing flood plain development. The Commission should work with the municipalities to ensure that they enforce the requirements. Development applicants should be required to assert that the areas in which they plan to build are not subject to flooding. A careful review of of soils, vegetation and flood hazard maps should, in most cases, identify the extent of flood plain areas. When there are any questions regarding the flood plain limit, detailed hydrologic and hydraulic analyses should be required to resolve them.

TABLE 6

SUMMARY OF STORMWATER MANAGEMENT TECHNIQUES

Management Technique	Objective: Reduce Peak Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Advantages	Disadvantages
Detention Ponds					
1. With a normal pool	X		Usu lly a earthen basin with a minimum pool of water at all times; outlet structure regulates outflow from the basin.	1. Can be used with a large tributary area 2. Highly effective for reducing peak flow rates 3. May have aesthetic or recreational benefits 4. Supplemental firewater source 5. Reduces suspended sediment load	1. Does not allow for significant infiltration 2. Can become a mosquito breeding ground 3. Considerable amount of land is required 4. Potential safety hazard unless properly secured
2. Without a normal pool	X		Usually an earthen basin which is dry between periods of precipitation; outlet structure regulates outflow from the basin.	1. Can be used with a large tributary area 2. Highly effective for reducing peak flow rates 3. Reduces suspended sediment load	1. Does not allow for significant infiltration 2. Ca become a mosquit o breeding ground 3. May become unsightly 4. Potential safety hazard unless properly secured
Parking Lot Storage	X		In large parking areas, typically a portion of the lot which is least frequently used; outflow structures are constructed in order to temporarily pond water.	1. Requi es no additio al area 2. No structural limit on depth of storage 3. Does not need to be level 4. May be combined with dutch drains or other seepage techniques and vegetated buffer ditches	1. Temporary aconvenience to car own es 2. Ice format on 3. Potential goundwa er pollution surce wen combined w th subsurface seepage te chiques 4. Detention the insuf i- ciently l g for flow lands we
Rooftop Storage					
1. Flat rooftops	X		Perforated strainers or gravel barriers surround downpipe inlets to regulate out low	Requires no additional area 2. May be combined with dutch drains or other seepage techniques and vegetated buffer ditches 3 Reduced air conditioning expense	1. Increased roof l ads 2. Leakage potential increased 3. Additional maintenance required

TABLE 6 (Continued)

Management Technique	Objective: Reduce Perk Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Advantages	Disadvantages
Rooftop Storage (Continued)					
2. Sloping rooftops	X		Gravel check drains retard flow velocity and temporarily pond small amounts of water	1. Requires no additional area 2. May be combined with dutch drains or other seepage techniques m d vegetated buffer ditches	1. Only minor reduction of perk flows 2. Increased leakage potential 3. Increased maintenance required
Dutch Drains	X	X	Gravel-filled ditches with an optional drainage pipe pipe at the base. May be covered by lattice blocks or steel grate	1. Maintains groundwater recharge 2. Provides water for vegetated buffer strips 3. Small surface rrer	1. Subject to clogging 2. May be unable lo contain runoff from exceptional storms 3. Potential for groundwater pollution
Porous Paving					
1. Asphalt	X	X	Base course of crushed gravel with a surface course of porous asphalt paving	1. No additional lrnd required 2. Maintain groundwater recharge 3. Water Is not stored on surface	1. Should not be used where excessive surface debris may cloy pores 2. Polenllrl for groundwater pollution 3. Cannot be used over seasonally hlyh water tables
2. Precast lattice blocks and bricks	X	X	Precast paving slabs which provide a hard surface and yet rro porous lo varying degrees	1. Flexible 2. Can be used between strips of impervious rsphrlt	1. Difficult and expensive lo install 2. Not as permeable as porous asphalt
Seepage Basin or Recharge Basin	X	X	Similar lo detention basins k t constructed in In areas of low water tables and high infiltration rates; generally uo not have outflow structures	1. Increased recharge of groundwater	1. Basin may loose recharge elficiency due to clogging 2. Potential for groundwater pollution
Seepage Pits or Dry Wells	X	X	Similar in concept, but for smaller areas than recharge basins	1. Increased recharge of groundwater	1. Possibility of clogging; may need maintenance
Seepage Beds	X	X	Similar lo seepage pits, but with addition of lateral distribution pipes	1. Increased recharge of groundwater 2. Clogging potential is less than with seepage pits due to larger rrer 3. Mr y be used under parking lots	1. Clogging potential

TABLE 6 (Continued)

Management Technique	Objective: Reduce Peak Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Appropriate Development	Potential Appropriate Portion of the Pinelands
Detention Ponds					
1. With a normal pool	X		Usually a earthen basin with a minimum pool of water at all times; outlet structure regulates outflow from the basin.	1. High density residential 2. Commercial and industrial areas	1. Areas with seasonally high water tables 2. Areas where recharge is less important
2. Without a normal pool	X		Usually an earthen basin which is dry between periods of precipitation; outlet structure regulates outflow from the basin.	1. High density residential 2. Commercial and industrial areas	1. Areas where recharge is less important
Parking Lot Storage	X		In large parking areas, typically a portion of the lot which is least frequently used; outflow structures are constructed in order to temporarily pond water	1. High desnity residential 2. Commercial and industrial areas	1. Areas where recharge is unimportant 2. Areas underlain by loamy soils (if combined with subsurface seepage)
Rooftop Storage					
1. Flat rooftops	X		Perforated strainers or gravel barriers surround downpipe inlets to regulate outflow	1. Large buildings	1. Areas where recharge unimportant unless combined with subsurface seepage
2. Sloping rooftops	X		Gravel chec[illegible]ons retard [illegible]ow veloci[illegible] temporarily pond [illegible] amounts of water	1. Small buildings	1. Areas where recharge unimportant unless combined with subsurface seepage
Dutch Drains	X	X	Gravel-filled ditches with an opt[illegible]nal drain[illegible]pipe pipe at the base. [illegible] be covere[illegible] by lattice [illegible]ks or steel grate	1. Individual residences, small buildings and parking lots	1. Medium and low density residential; lightly used road shoulders

TABLE 6 (Continued)

Management Technique	Objective: Reduce Peak Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Appropriate Development	Potential Appropriate Portion of the Pinelands
Porous Paving					
1. Asphalt	X	X	Base course of crushed gravel with a surface course of porous asphalt paving	1. Residential, commercial or light industrial parking areas	1. All areas o high infil- tration rat s if concen- tration of pollution sources is ow
2. Precast lattice blocks and bricks	X	X	Precast paving slabs which provide a hard surface and yet are porous to varying degrees	1. All types of develop- ment for small ground areas	1. All areas of de el pmen
Seepage Basin or Recharge Basin	X	X	Similar to detention basins but constructed in in areas of low water tables and high infiltra- tion rates; generally do not have outflow structures	1. All types of develop- ment	1. Areas where reduction in groundwater quality will not pose problems
Seepage Pits or Dry Wells	X	X	Similar in concept, but for smaller areas than recharge basins	1. Individual home sites in single or cluster development; small buildings	1. All areas with suffi- ciently low water tables
Seepage Beds	X	X	Similar to seepage pits, but with addition of lateral distribution pipes	1. Individual home sites in single or cluster development; small buildings	1. All areas with suffi- ciently low water tables

Source: Betz-Converse-Murdoch-Inc.

Any changes which decrease resistance to flow and thus increase flow velocity will increase downstream flood flow rates. Therefore, alteration should not be permitted except by special exception. Conversion of natural vegetation to cranberry bogs should have little impact on peak flow rates because the diking system used to form the bogs acts in a manner similar to natural vegetation in retarding the rate of flood flow.

All hazardous materials should be prohibited from flood plain areas due to the threat of the materials mixing with flood waters.

RECOMMENDATIONS FOR FUTURE STUDIES

Four major recommendations for future studies are presented based on the findings of this surface water hydrology analysis.

1. Continuously recording streamflow gaging stations are maintained near the downstream limit of most major Pinelands drainage basins. However, with the exception of the Great Egg Harbor River Basin, only one continuous recording station--McDonalds Branch--is active on smaller tributaries. Additional information on the characteristics of streamflow in small sub-drainage basins is necessary to establish a better understanding of intra-basin and inter-basin groundwater transfer, rainfall-runoff relationships, and low flow stream characteristics. Therefore, it is recommended that additional continuous recording stations be established and the non-recording network expanded. The proper design of stormwater management facilities depends on a reasonably accurate understanding of the rate and volume of stormwater runoff. In addition, precipitation monitoring stations should be established within or near the gaged basins.

2. The Soil Conservation Service's hydrologic soil groups and R-20 computer model were used during the current study. On a preliminary basis, this methodology appears to be a reasonable approach for estimating runoff-producing areas and calculating peak flow rates for both natural and urban land uses. However, considerable additional field investigations and computer modeling of the runoff characteristics of small and moderate sized Pinelands drainage basins should be conducted as soon as possible. The principal objective of this investigation will be to develop any necessary modifications to the assumptions in the SCS's computational methodology in order to develop a good method for calculating stormwater runoff potential in the Pinelands.

Q_L = The same as Q_{AV} except for a nearby hydrologically similar basin with a relatively long period of record

Q_S = The same as Q_L except using a period of record which matches the one used in Q_{AV}

Q = The adjusted flow which occurs at a specified frequency

The adjustment factors used at the various stations and the basins from which they were derived are shown in Table 5.

TABLE 5

FLOW DURATION ADJUSTMENT FACTORS

	1409280	1410787 1410810 1410820 1411300	1409810
99% Factor	.99	.93	1.05
90% Factor	.98	.93	1.04
70% Factor	.96	.91	1.03
SOX Factor	.94	.91	1.03
30% Factor	.95	.87	1.06
10% Factor	.96	.84	1.09
1% Factor	.96	.83	1.11
Stations Derived from	01409095	01411000	01409500

Source: USGS, 1979
Analysis: BCM

As a result of the different size of the watersheds and a need to compare them on an equitable basis, it is desirable to use a parameter which neglects the size of the drainage area, To satisfy these requirements, the units of the streamflow quantity measurement is changed to cubic feet per second per square mile of drainage area (cfs/sq.mi.).

Duration curves are prepared by analyzing past data, which may or may not be repeated in the future. If the record spans a representative range of meteorological events over a long period, the data may be used to estimate the probability of occurrence of a specffied discharge, The slopes of duration curves are particularly useful as an Indicator of unusual natural hydrologfc conditfons and/or man-made modifications to a basin's hydrologfc system, including: uncommon sofl characteristics, intra- or inter-basin transfer, channel modification, reservoirs, measurement error or fnsufficient length of record. Undisturbed Pinelands streams have a fairly uniform flow, even during periods of draught. The relatively flat curve for the Batsto Rfver at Batsto (Figure 10A) is representative of the majority of duratfon curves of Pinelands streams. A very atypical curve, that of Absecon Creek, is plotted in Figure 10D.

The curves of each gaged Pinelands stream are presented in Figures 10A through 10E. To facilftate intra-basin comparisons, the curves have been arranged so that streams within the same basin or similar adjacent basins are plotted together using the same vertfcal scale (cfs/mi^2). The characteristics of each duration curve and probable explanations of anomalous curves are contained in the following paragraphs.

<u>Intra-Basin Observations</u>

<u>Mullica Basin:</u> The curves for the Mullica River Basin are shown in Figure 10A. It is readily apparent that the basin has two groups of streams wfth sfmflar flow patterns. Each group contains. two streams: the Mullica Rfver and the West Branch Wading River, and the Batsto River and Oswego Creek. Of particular interest is the area between the 60 and 90 percent lines. The Mullica Rfver and West Branch Wading River both show the same perterbation at these points. This discontinufty translates fnto a proportionate reduction in runoff production at low flows when compared to the other streams in the basin. The other two stations in thfs basin have smooth and uniform curves, displaying no particularly unusual or distinguishing characteristics between intra-basin comparisons. Note that except for the perterbations at the 60-80 percentile, all four stations produce curves which have essentially the same slope and shape.

Betz · Converse · Murdoch · Inc. BCM

Source: USGS 1979 ; BCM Analysis

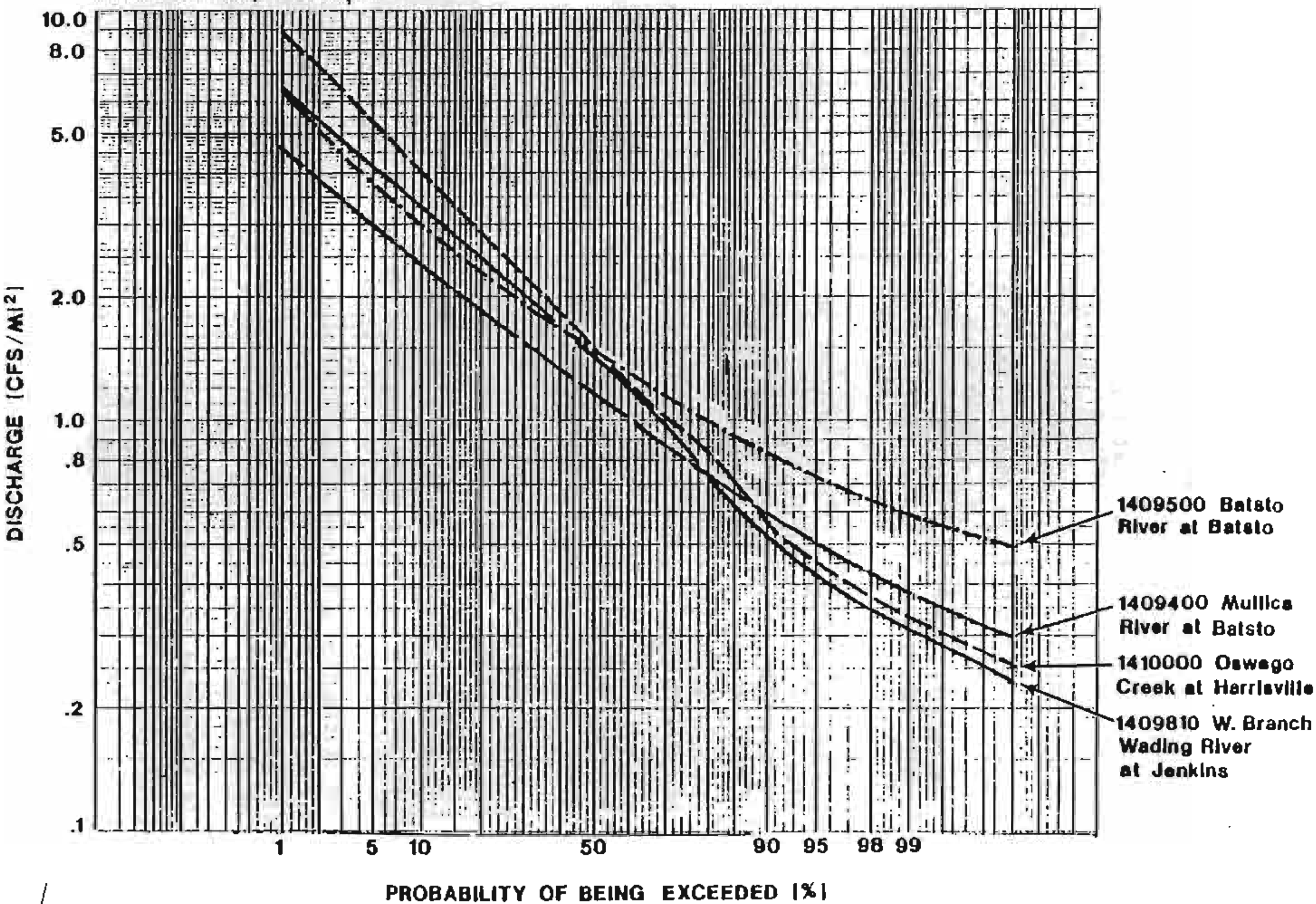

Figure 10A. FLOW DURATION CURVES - MULLICA RIVER BASIN

The Oswego Creek and the Batsto River flow duration curves have the same shape but different magnitudes. It is probable that this difference is attributable to basin transfer. As discussed in the section on hydrologic budgets, there is a net transfer of water out of Oswego Creek and a net transfer into the Batsto River Basin. Because the curves have the same shape, the transfer is likely to occur at the same rate, independent of the flow rate in the streams.

The discontinuity of the plot for the Mullica River near the 70 percent point may be attributable to human modification. A past effort to channelize and realign Sleeper Branch (a tributary to the Mullica) may be the primary contributing factor. The gage is located between the point where Sleeper Branch formerly entered the Mullica and where it enters now.

Because the original path of Sleeper Branch is still shown on topographic maps of the area, it is conceivable that the re-aligned portion creates a more significant diversion during moderate and higher flow periods than during periods of low flow. This type of phenomena would account reasonably well for the rather abrupt drop in the curve.

The West Branch Wading River has similar characteristtcs to the Mullica near the 70 percent point; however, they are likely to be caused by different reasons. The probable causes of the perterbation for the .West Branch Wading River curve are the short period of record and flow fluctuations caused by intermittent flooding and draining of the large number of cranberry bogs in the watershed.

<u>Great Egg Harbor River Basin</u>: The graph .for the Great Egg Harbor Basin is shown in Figure 108. The curves for Great Egg Harbor at Folsom, Great Egg Harbor at Blue Anchor, and Fourmile Branch are the same slope, shape and magnitude. This implies that all three watersheds produce similar quantities of runoff over the full range of precipitation input and, hence, display similar hydrologic response characteristlcs.

The station for a Great Egg Harbor Tributary at Sicklersville also has a smooth and constant curve, but it has a dramatically different shape. Based on unit area, this stream has higher high flows and lower low flows that the other streams in this basin. The low flows, however, vary much more from the other streams than do the high flows..

The difference indicated in a Great Egg Harbor tributary at Sicklersville is probably a result of two factors: soils and human modification. The soils upstream from the Sicklersville gage have loamy subsoils and high water table conditions. In' addition, approximately 25%

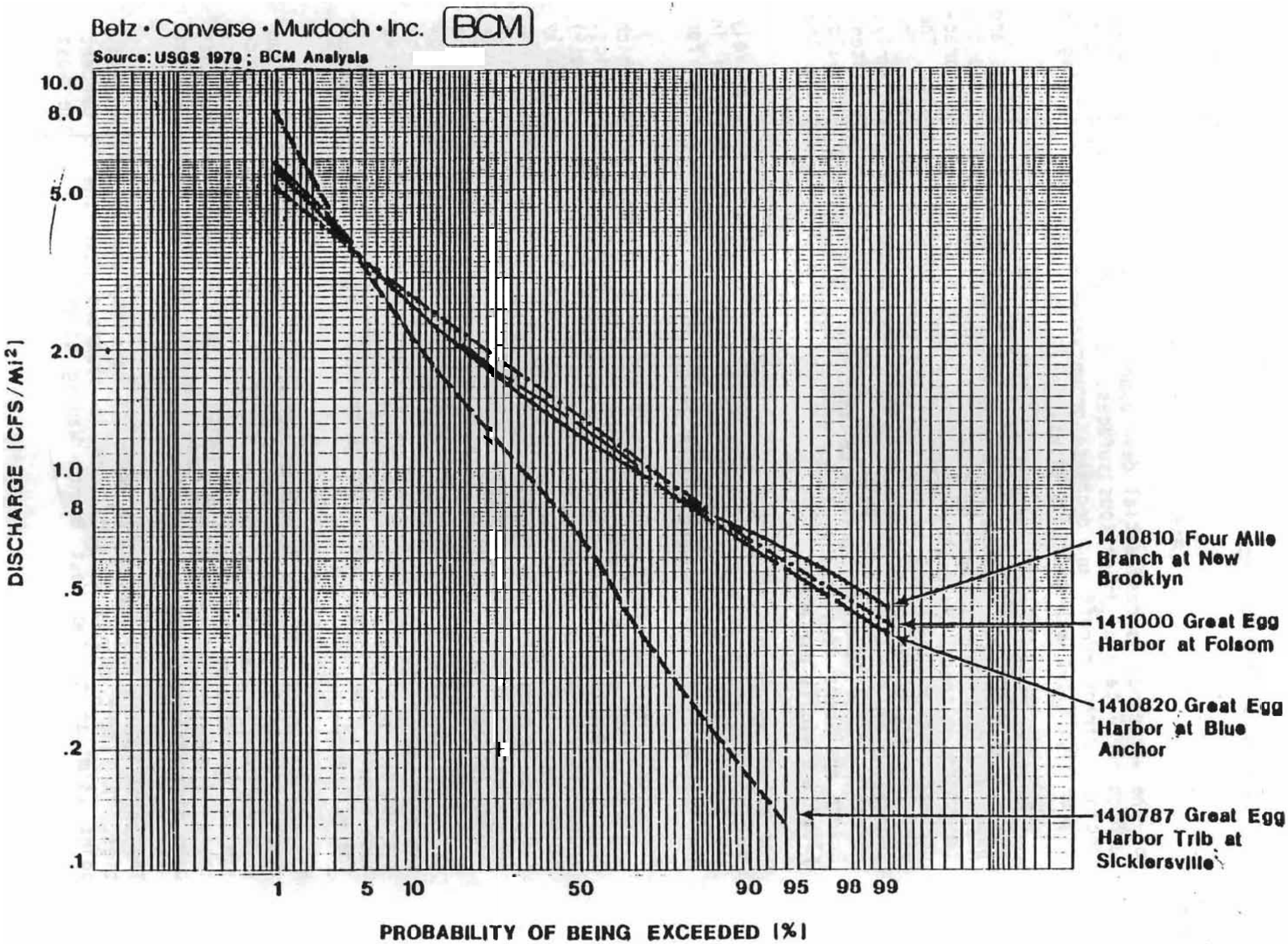

Figure 10B. FLOW DURATION CURVES - GREAT EGG HARBOR RIVER BASIN of the watershed is residential development, a condition which produces a high percentage of impervious sufaces. Both of these factors tend to increase direct runoff and decrease groundwater recharge, resulting in higher high flows and lower low flows.

Rancocas Creek Basins: The plots for the Rancocas Creek Basins are shown in Figure 10C. McDonalds Branch at Lebanon State forest and the North and South Branch Rancocas creeks all display similar curve characteristics, although McDonalds Branch does have a different shape. The curve for Mt. Misery Brook is substantially different at low flows. The very low flows for this stream are approached almost perpendicularly, indicating that the stream could nearly be classed as an intermittent stream. It is interesting to note that the high flows for McDonalds Branch are about identical to those for Mt. Misery Branch, but the low flows are widely different.

The other two curves (South and North Branch Rancocas) show relatively smooth, continuous curves, although there is a slight perterbation in the South Branch similar to, though not as severe as, the one noted for the Mullica River and the West Branch Wading River.

Three of the four streams in this basin have cfs/mi^2 curves which exhibit distinguishing and reasonably explainable characteristics. McDonalds Branch is generally displaced to the left (lower cfs/mi^2) except in the higher percent portion of the graph. This is probably caused by a combination of two factors: soils and basin transfer. The McDonalds Branch watershed is characterized by soils with extremely high infiltration rates. Consequently, the percentage of rainfall that becomes direct storm runoff is extremely low, and infiltration to the groundwater reservoir is exceptionally high and the resulting base flow is relatively high. This higher baseflow satisfactorily explains why the portion of the curve at low flow is concave upward (the low flows are not as low as expected). The overall reduction in the curve magnitude results from a net intra- and inter-basin transfer of water out of the watershed.

The curve for Mt. Misery Branch at Lebanon State Forest has a marked downward concavity, indicating very low to no flows at the high exceedence end of the distribution. The Mt. Misery Branch has characteristics similar to those of the McDonalds Branch. The USGS has documented that there is substantial groundwater underflow at the gage. The gage has been discontinued.

The South Branch Rancocas curve does not have any serious discontinuities. A slight change in curvature is apparent near the 70 percent point (similar to the West Branch Wading River). As with the West

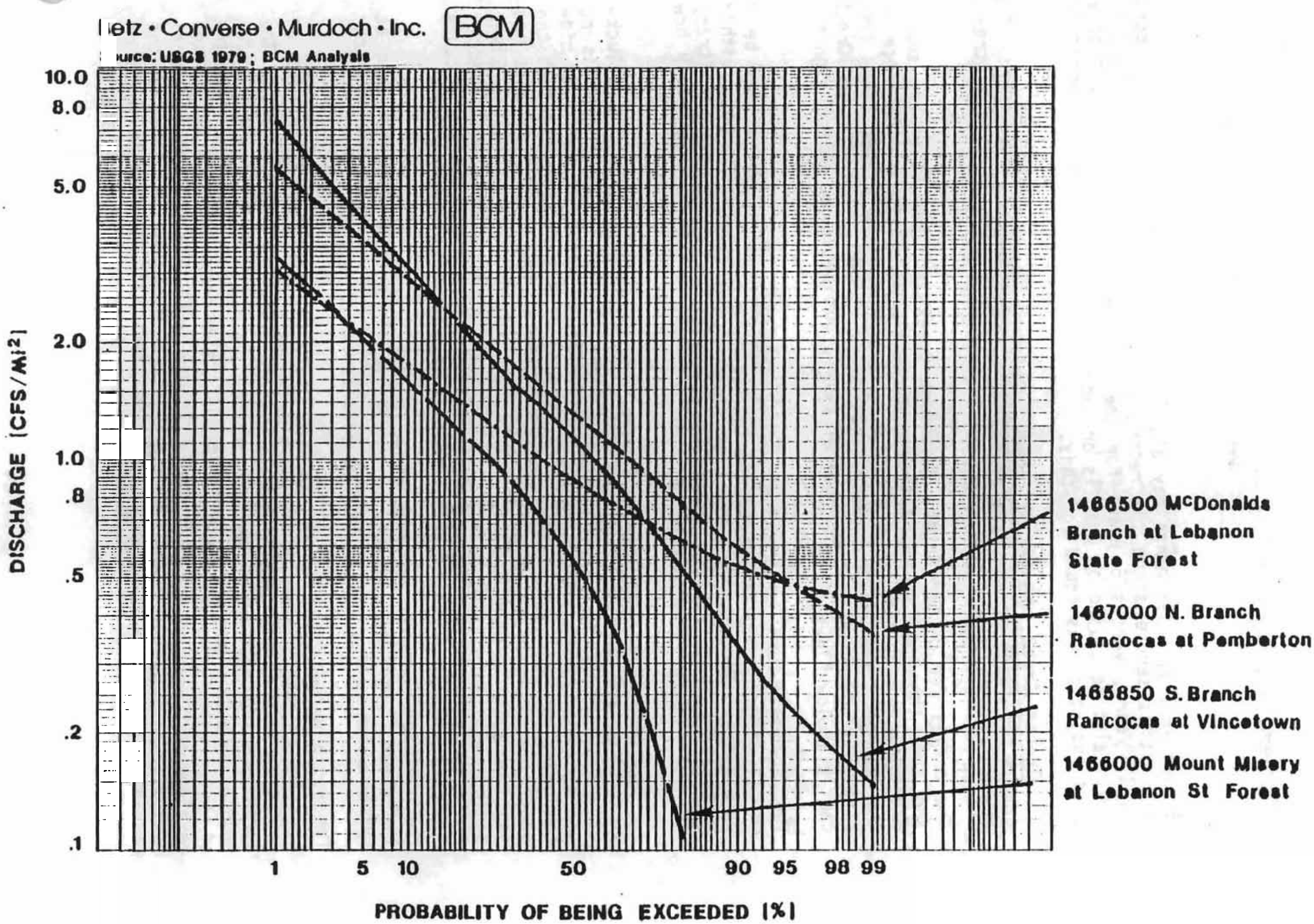

Figure 10 C. FLOW DURATION CURVES – RANCOCAS CREEK BASIN

Branch Wading, this change may also be due to a short period of record, but not as severe since the record period at the South Branch Rancocas is 13 years, versus 6 years for the West Branch Wading. The problem could also be caused by a soils or land use variation, but no particular substantiation was found for this.

Oyster Creek, Westecunk Creek, Cedar Creek and Toms River: The graphs for these streams are presented in Figure 10D. All four streams drain eastward toward the coast.

The curves for Oyster Creek, Westecunk Creek and Toms River are smooth and have the same shape, although there is an obvious difference in magnitude due to the large transfer of groundwater to Oyster Creek from the Oswego Creek Basin. Note that Cedar Creek and Westecunk Creek display similar properties at high flows, but begin to differ significantly at low flows.

The downward turn at the low end of the Cedar Creek curve may be a result of an irregularity caused by flooding of cranberry bogs within this basin. Because the effect of this flooding is somewhat arbitrary in relation to this plot, it is not possible to predict absolutely how the flooding would be manifested.

Tuckahoe River and Absecon Creek: The duration curves of the Tuckahoe River and Absecon Creek are presented in Figure 10E. There is no apparent rational explanation for the change in curvature near the midpoint of the Tuckahoe River curve. Several of the factors cited at the beginning of this section may be the reason. Note that the curve has generally the same shape as the ones for the West Branch Wading River and the South Branch Rancocas, both of which have been identified as having relatively short periods of record. This may also be the cause for this change in the Tuckahoe Basin (eight years of record).

The plot for the Absecon Creek shows it has a definite downward turn at low flows. This is probably caused by the Atlantic City public water system which relies on the Absecon as a source of supply.

The ratio between the discharges likely to be exceeded 10% and 90% of the time at each streamflow gaging station is presented in Table 6. The lower the ratio, the greater the uniformity of flow. The highest regularity was observed at Oyster, Westecunk, and Cedar creeks and McDonalds Branch. Factors accounting for the uniformity were the high percentage of soils with high infiltration rates, lack of urban or agricultural development, and inter-basin transfer of groundwater to three of the basins. The greatest variability of the gages with 10 or more years of record was observed at the Mullica River, Absecon Creek and the North

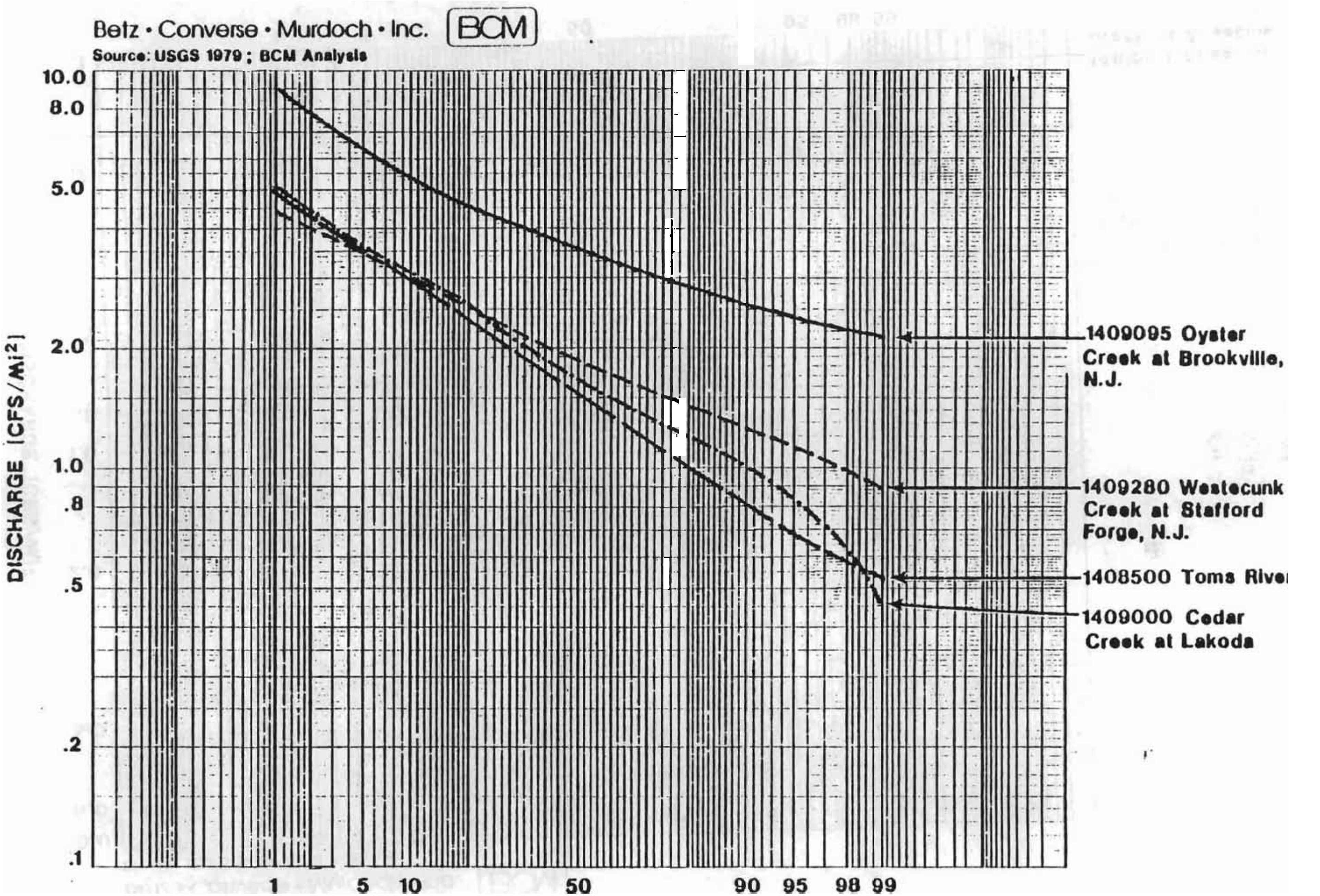

Figure 10D. FLOW DURATION CURVES – TOMS RIVER, CEDAR CREEK, OYSTER CREEK, WESTECUNK CREEK BASINS

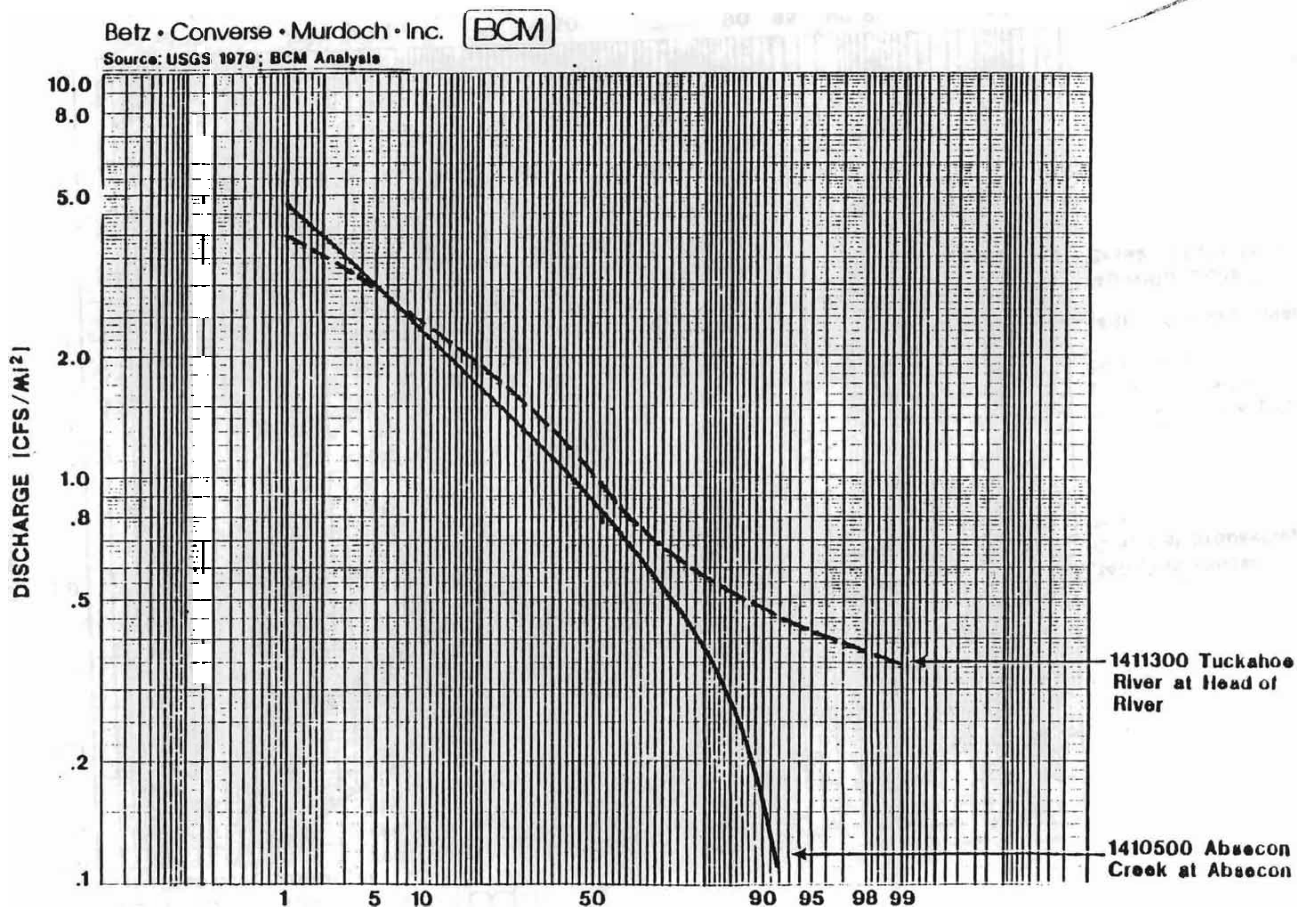

Figure 10 E. FLOW DURATIO[illegible] CURVES – TUCKAHOE RIVER, ABSECON CREEK BASINS

TABLE 6

COMPARISON OF STREAMFLOW DURATION VARIABILITY

Stream Name and Location	Period of Record (Water Years)	Drainage Area (mi^2)	Discharge (cfs) likely to be Exceeded: 10% of the Year	Discharge (cfs) likely to be Exceeded: 90% of the Year	Ratio of 10% to 90% Discharge
Toms River near Toms River	1929-78	124.0	2.95	.81	3.6
Cedar Creek near Lakoda	1933-58, 1971	56.0	3.05	1.02	3.0
Oyster Creak near Brookville	1966-78	7.43	5.5	2.6	2.1
Westecunk Creek at Stafford Forge	1974-78	16.0	3.05	1.28	2.4
Mullica River near Batsto	1958-78	64.4	3.3	.52	6.3
Batsto River at Batsto	1927-78	70.5	2.95	.83	3.6
West Branch Wading River near Jenkins	1975-78	84.1	4.0	.57	7.0
Oswego River at Harrisville	1931-1978	64.0	2.4	.6	4.0
Absecon Creek at Absecon	1924-28,33,-38,47-78	16.6	2.3	.16	14.4
Great Egg Harbor River Tributary at Sicklersville	1973-78	1.64	2.15	.17	12.6
four Mile Branch at New Brooklyn NJ	1973-78	7.74	2.6	.69	3.7
Great Egg Harbor River near Blue Anchor	1973-78	37.3	2.7	.64	4.2
Great Egg Harbor River at Folsom	1925-78	56.3	2.6	.66	3.9
Tuckahoe River at Head of River	1971-78	30.8	2.45	.49	5.0
South Branch Rancocas Creek at Vincentown	1962-75	64.5	3.1	.33	9.4
McDonalds Branch in Lebanon State Forest	1965-78	2.37	1.73	.53	3.3
North Branch Rancocas Creek at Pemberton	1921-78	111.0	2.9	.59	4.9

and South Branch Rancocas creeks. Higher runoff-producing soils, pumping of water for water supply, channel modifications, regulation for cranberry propagation, and loss of water due to inter-basin transfer, are factors accounting for the greater variability of flow in these basins.

Peak Flow Magnitude and Freauency

Peak flood flow rates for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods were computed* for all gaged streams with over 10 years of record (Table 7). Pinelands streams have relatively low peak flow rates and, under natural conditions, are not susceptible to flash flooding. During and after extreme rainfall events, flow rates gradually increase until they reach a peak after a day or mare, and then they gradually recede. Of the 11 Pinelands streams analyzed, Oyster Creek has the highest peak flows on a unit area basis. Accounting for the relatively high Osyter Creek flow rates are the relative steepness of the drainage basin and its small area.

tow Flow Magnitude and Freauency

The ability of streamflow to assimilate liquid wastes and provide water for municipal or industrial supply, conventional irrigation or cranberry bog flooding, suitable conditions for fish and other aquatic organisms and water-based recreation, is commonly evaluated in terms of low flow characteristics. In this section, the low flow characteristics at each gaging station are described using frequency curves.

The concept used for the analysis is to define a recurrence interval, or return period, for particular flow events. The return interval, RI, is the average number of years during which an item of a given magnitude may be expected to occur once and is mathematically equal to the reciprocal of the frequency. A computer program was used to select the annual minimum flow for each recurrence interval; compute the mean, standard deviation, and coefficient of skew; plot the fitted Log Pearson Type III probability distribution, and calculate the individual annual minimum flows versus recurrence interval using the plotting position formula:

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* The Log Pearson Type III statistical analysis of gaged records using a combination of local and regional skew coefficients as recommended by the U.S. Water Resources Council (WRC Bulletin 17-A, 1978) was used far the computations.

TABLE 7

PEM FLOOD FLOW RATES

Station	Number	Period of Record	Drainage Area mi^2	Average Daily Discharge cfs	Average Daily Discharge cfs/mi^2	Q2 cfs	Q2 cfs/mi^2	Q5 cfs	Q5 cfs/mi^2	Q10 cfs	Q10 cfs/mi^2	Q25 cfs	Q25 cfs/mi^2
Toms River near Toms River	01408500	50	124.0	215.0	1.7	744.0	6.0	1070.0	8.6	1320.0	10.6	1680.0	13.5
Cedar Creek near Lakoda	01409000	26	56.0	107.0	1.91	413.0	7.4	567.0	10.1	686.0	12.3	857.0	15.3
Oyster Creek near Brookville	01409095	13	7.4	28.1	3.8	108.0	14.5	156.0	21.0	195.0	26.2	252.0	33.9
Mullicr River near Batsto	01409400	21	64.4	112.0	1.7	515.0	8.0	839.0	13.0	1120.0	17.4	1580.0	24.5
Batsto River at Batsto	01409500	50	70.5	126.0	1.8	512.0	7.3	806.0	11.4	1040.0	14.8	1400.0	19.9
Oswgo River rt Harrisville	01410000	48	64.0	88.0	1.4	345.0	5.4	535.0	8.4	695.0	10.9	944.0	14.8
Great Egg Harbor River at Folsom	01411000	53	56.3	86.5	1.5	283.0	5.0	449.0	8.0	591.0	10.5	813.0	14.4
Manantico Creek near Millville	01412000	27	22.3	37.7	1.7	198.0	8.9	357.0	16.0	510.0	22.9	771.0	34.6
South Branch Rancocas Creek at Vincintown	01465850	17	65.5	93.7	1.5	781.0	11.9	979.0	14.9	1120.0	17.1	1310.0	20.0
Mt. Misery Brook in Lebanon State Forest	01466000	25	2.7	1.93	0.7	12.6	4.6	22.0	8.1	30.9	11.3	45.8	16.8
McDonalds Branch in Lebanon State Forest	01466500	25	2.3	2.32	1.0	10.0	4.3	16.5	7.1	22.4	9.7	31.9	13.8
North Branch Rancocas Creek at Pemberton	01467000	37	111.0	171.0	1.54	743.0	6.7	1080.0	9.7	1350.0	12.2	1740.0	15.7

TABLE 7 (Continued)

Station	Number	Period of Record	Drainage Area mi^2	Q50 cfs	Q50 cfs/mi^2	Q100 cfs	Q100 cfs/mi^2	Q500 cfs	Q500 cfs/mi^2
Toms River near Toms River	01408500	50	124.0	1990.0	16.0	2330.0	18.8	3270.0	26.4
Cedar Creek near Lakoda	01409000	26	56.0	999.0	17.8	1160.0	20.7	1590.0	28.4
Oyster Creek near Brookville	01409095	13	7.4	302.0	40.6	357.0	48.0	517.0	69.6
Mullica River near Batsto	01409400	21	64.4	2010.0	31.2	2510.0	39.0	4090.0	63.5
Batsto River at Batsto	01409500	50	70.5	1710.0	24.3	2060.0	29.2	3050.0	43.3
Oswego River at Harrisville	01410000	40	64.0	1170.0	18.3	1430.0	22.3	2210.0	34.5
Great Egg Harbor River at Folsom	01411000	53	56.3	1010	17.9	1250.0	22.2	1960.0	34.8
Manantico Creek near Millville	01412000	27	22.3	1030	46.2	1350.0	60.5	2440.0	109.4
South Branch Rancocas Creek at Vincintown	01465850	17	65.5	1470.0	22.4	1630.0	24.9	2040.0	31.1
Mt. Misery Brook in Lebanon State Forest	01466000	25	2.7	60.3	22.1	78.3	28.7	138.0	50.5
McDonalds Branch in Lebanon State Forest	01466500	25	2.3	40.9	17.7	51.6	22.3	85.6	37.1
North Branch Rancocas Creek at Pemberton	01467000	37	111.0	2070.0	18.6	2440.0	22.0	3460.0	31.2

$$RI = \frac{(n + 1)}{m}$$

where:

RI = Return Interval

n = The rank of the event (n = 1 for maximum event and n = m for minimum event)

m = The number of years of record

It is very important that for this type of frequency analysis there is no implication that a particular event will occur at even reasonably constant intervals. That is, a five-year event may be expected to occur once every five years on the average, but may be distributed such that it occurs two years in a row or only once in 10 years.

i s concept can be readily applied to low flow events by selecting representative low flow periods and applying this process. A low flow event is usually described as an X-day low flow. This essentially defines the lowest flow rate which has occurred over X number of days during the period of record, Results of the analyses of the 1-, 3-, 7-, 14-, 30-, 60-, 90-, 120-, 183-, and 365-day low flows with calculated return periods varying from 1 year to 200 years are presented in Appendix 1 and summarized in Table 8. The low flow frequency plot of the Mullica River near Batsto is presented in Figure 11.

Caution should be exercised in comparing the curves of one station with another station to ensure that the variations in the scale (discharge) are taken into account. The type of information which can be derived from these plots relates to the length of time in which a given low flow can be expected to occur. This information may, in turn, be utilized as a partial basis for determining the type of land use and associated water-consuming activity may be appropriate for the basin involved. For instance, a land use activity which cannot tolerate frequent lows, below a certain minimum, such as a point source discharge of wastewater, should not be placed in basins which have frequent streamflows below the minimum.

Two of the plots are of particular interest, Absecon Creek and Batsto River. Absecon Creek has low flows which have values that are similar in magnitude to McDonalds Branch, a basin of substantially smaller drainage area. The Batsto River has frequency curves which are not

TABLE 3

SUMMARIES OF LOW FLOW FREQUENCY ANALYSIS

Location	Recurrence Interval (Years)	Day Low Flow (cfs) 7	30	90
Toms Riva	100	52.5	56.9	70.2
	50	53.4	60.3	74.9
	20	60.3	66.1	82.5
	10	65.0	71.9	90.0
	5	71.3	79.8	100.1
	2	85.6	98.1	123.1
Cedar Creek near Lakoda	100	27.4	37.8	42.0
	50	29.2	40.2	45.3
	20	32.1	43.9	50.4
	10	34.8	47.4	55.1
	5	38.4	51.8	60.9
	2	46.2	60.8	71.9
Westecunk Creek at Stafford Forge	100	6.8	11.6	14.9
	50	7.5	12.3	15.4
	20	8.6	13.5	16.4
	10	9.8	14.6	17.4
	5	11.3	16.1	18.8
	2	15.0	19.4	22.4
Oswego River at Harrisville	100	15.7	20.7	24.6
	50	17.0	22.0	26.8
	20	19.3	24.3	30.3
	10	21.5	26.6	33.8
	5	24.6	29.8	38.5
	2	31.0	37.6	49.4
Absecon Creek at Absecon	100	.02	.09	.39
	50	.04	.16	.63
	20	.11	.35	1.20
	10	.24	.67	2.01
	5	.59	1.38	3.50
	2	2.50	4.32	8.17
Great Egg Harbor River Tributary at Sicklersville	100	.02	.02	.08
	50	.03	.03	.11
	20	.05	.06	.17
	10	.07	.11	.23
	5	.11	.19	.35
	2	.22	.41	.70
Four Mile Branch at New Brooklyn	100	2.4	2.5	3.5
	50	2.7	2.8	3.8
	20	3.2	3.3	4.2
	10	3.5	3.8	4.7
	5	4.2	4.4	5.3
	2	5.2	5.8	7.0
Great Egg Harbor River at Blue Anchor	100	9.4	9.9	12.9
	50	10.2	11.1	14.1
	20	11.7	13.1	16.3
	10	13.3	15.2	18.6
	5	15.5	18.1	22.1
	2	21.2	25.1	32.0
Great Egg Harbor Riva st Folsom	100	16.3	17.6	21.5
	50	17.6	19.2	23.5
	20	19.8	21.8	26.8
	10	22.0	24.4	30.1
	5	24.9	27.9	34.7
	2	31.6	36.2	45.7

TABLE 8 (Continued)

Location	Recurrence Interval (Years)	Day Low Flow (cfs) 7	30	30
Tuckahoe River at Head of River	100	7.8	9.7	11.6
	50	8.2	10.2	12.2
	20	8.9	11.0	13.2
	10	9.5	11.7	14.2
	5	10.3	12.6	15.7
	2	12.0	14.3	19.4
Maurice River	100	24.4	28.5	35.5
	50	27.2	31.8	39.8
	20	31.9	37.3	47.0
	10	36.7	42.9	54.4
	5	43.3	50.8	64.6
	2	58.6	69.3	88.7
Manantico Creek near Millville	100	4.1	9.3	11.3
	50	4.8	10.1	12.4
	20	5.0	11.5	14.3
	10	7.3	12.8	16.0
	5	9.0	14.5	18.3
	2	12.9	17.9	22.9
South Branch Rancocas Creek at Vincentown	la,	5.3	7.2	10.6
	50	6.0	8.2	12.0
	20	7.1	9.8	14.4
	10	8.3	11.6	16.9
	5	9.9	14.1	20.7
	2	13.9	20.4	30.5
Mt. Misery Brook fn Lebanon State Fast	la,	.001	.004	.079
	50	.002	.006	.092
	20	.003	.010	.118
	10	.006	.016	.150
	5	.012	.030	.207
	2	.060	.117	.418
McDonald's Branch in Lebanon State Forest	100	.86	.87	.90
	50	.88	.89	.93
	20	.91	.93	1.00
	10	.95	.98	1.07
	5	1.00	1.05	1.17
	2	1.16	1.25	1.42
North Branch Rancocas Creek at Pemberton	la,	25.8	33.9	41.7
	50	27.8	36.2	45.2
	20	31.3	40.2	51.0
	10	34.9	44.1	56.9
	5	39.9	49.9	65.1
	2	52.2	64.0	84.7
Oyster Creek near Brookville	la,	12.7	14.1	15.5
	50	13.3	14.8	16.3
	20	14.4	15.9	17.5
	10	15.3	16.8	18.7
	5	16.5	18.0	20.0
	2	18.8	20.2	22.7
Mullica River near Batsto	100	8.4	12.8	16.5
	50	10.0	14.3	18.5
	20	12.7	17.0	22.0
	10	15.6	19.8	25.7
	5	19.7	24.0	31.2
	2	29.9	34.7	46.0

TABLE 8 (Continued)

Location	Recurrence Interval (Years)	3ay Low Flow (cfs) 7	30	30
Batsto River at Batsto	100	35.2	37.1	39.4
	50	36.6	38.8	42.1
	20	38.8	41.7	46.6
	10	41.1	44.5	51.0
	5	44.3	48.5	56.9
	2	52.0	58.1	70.6
West Branch Wading River near Jenkins	100	19.0	18.9	25.0
	50	19.9	20.1	26.6
	20	21.5	22.3	29.8
	10	23.4	24.8	33.7
	5	26.3	28.6	40.3
	2	34.8	39.8	62.3

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Source: USGS 1979; BCM Analysis

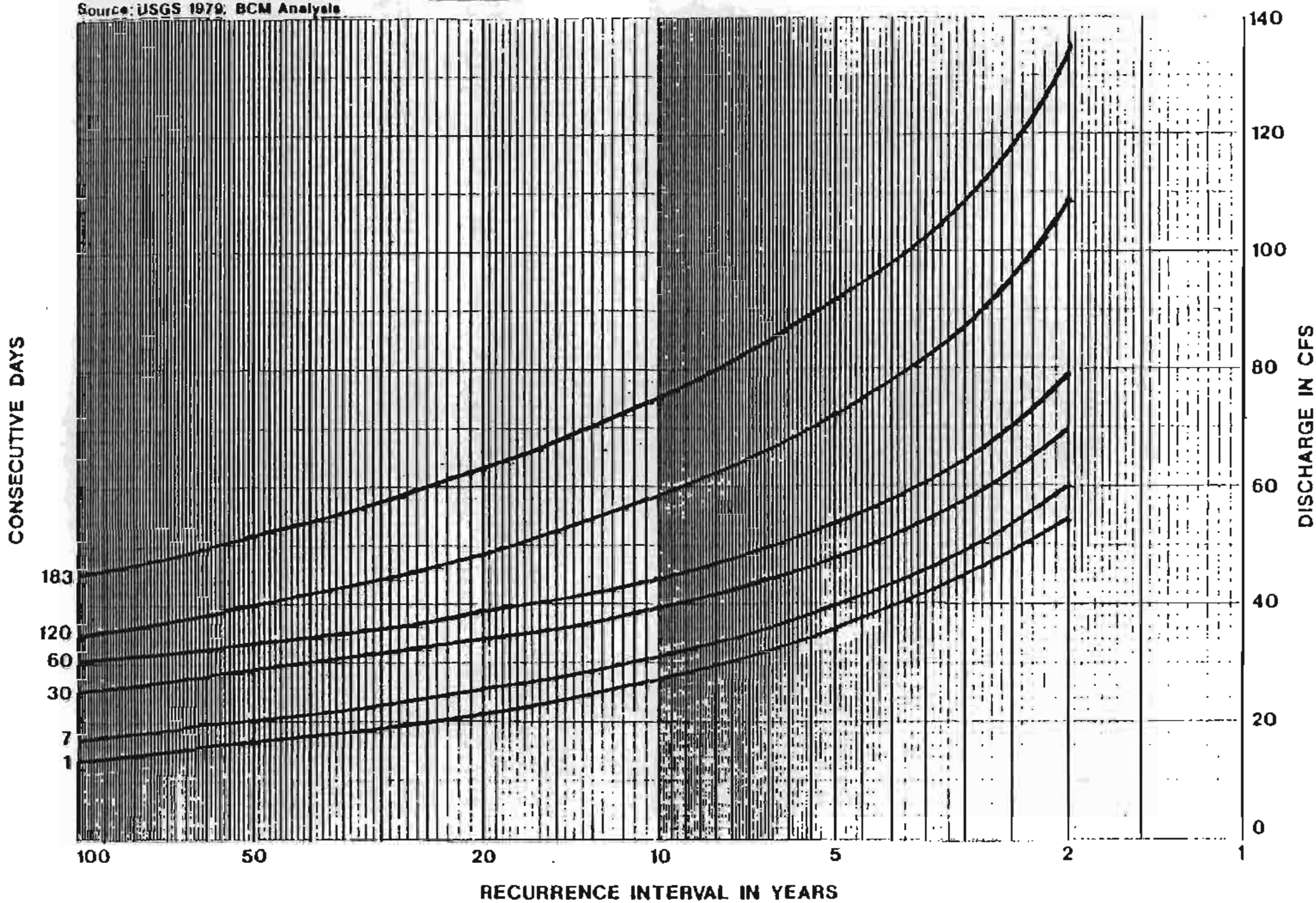

Figure 11. LOW FLOW FREQUENCY CURVES-MULLICA RIVER NEAR BATSTO (01400400)

particularly distinguishing except for the 1-day low flow. The 1-day low flow is much lower than the 7-day low flow, when compared with the other streams. The Absecon Creek and Batsto River low flow frequency features are probably attributable to soils and human modifications.

Hydrologic Budgets

With the input data adjusted as described earlfer, the hydrologic budgets can now be completed using Rhodehamel's budget eauatfon. Budgets are performed for the basins and sub-basfns listed fn Table 9. The procedure is to use the fso-hyet (Figure 5) and iso-ET (Figure 6) maps to obtain precfpitation and evapotranspiration within each basin, and to calculate runoff using the equation: Runoff (R) = Precipitation (P) - Evapotranspiration (ET). The runoff quantity obtained fn this manner can then be compared to the measured surface runoff at stream gages and the differences noted.

The results. of this analysis of Pinelands drainage basfns are presented in Table 9. There are two additional columns in the table, "Adjusted R" and "Estimated R." The adjusted R is used to modify the measured R on basins where the gage is sufficiently upstream of the basin outlet so as to not be completely representative of the entire basin. This adjustment is made by weighting the R of the gaged portion of the watershed with the calculated R of the basin downstream of the gage and fs noted by an asterisk in the measured R column. The adjusted R is listed appropriately. The estfmated R is used in basins where there are no gages. The estimated R is set equal to the calculated R except In basins where some transfer of water into or out of the basin is expected. This transfer is expected, on the basis of earlier discussions, to the ungaged Forked River and Mill Creek basins. The amount of estimated R of the Forked Rfver is derived by using the same unit flow as Cedar Creek because of their geographic proximity. The estimated R for Mi11 Creek is obtained by averaging the flows from Westcunk Creek and Cedar Creek for the same reason.

The difference volume, measured in inch-square miles, is listed in the last column. It is useful to identify where and how much basin transfer is defined by the dffference volume.

Transfer from North Branch Rancocas into Cedar Creek fs probable. A mass balance indicates that the unaccounted for quantity in the North Branch Rancocas (-166.5) is very nearly equal to the excess in Cedar Creek (+162.4).

TMLE 9

BUDGET ANALYSIS DATA

Basins	Precipitation (inches)	Evapotranspiration (inches)	Calculated Runoff (Inches)	Runoff (inches)* Measured	Adjusted	Estimated	Difference** (inches)	Difference Vol. in-mi²
Toms River	45.6	22.3	23.5	23.5	---	---	0.0	---
Rancocas River Basin	44.7	22.6	22.1	---	---	---	---	---
Worth Branch Rancocas	45.0	22.6	22.4	20.9	---	---	- 1.5	-166.5
South Branch Rancocas	44.1	22.5	21.6	19.7	---	---	- 1.9	-122.6
Cedar Creek	44.4	21.4	23.0	25.9	---	---	2.9	+162.4
Forked River Basin	43.8	20.5	23.3	---	---	---	---	---
Forked River	43.9	20.8	23.1	---	---	25.9	+ 2.8	+ 43.1
Oyster Creek	43.6	20.6	23.0	51.4***	41.0	---	+18.0	+207.0
Mill Creek	42.7	20.4	22.3	---	---	27.2	+ 4.9	+100.0
Westecunk Creek	43.9	20.5	23.4	26.7	---	---	+ 3.3	+ 52.8
Mullica River Basin	44.7	21.6	23.1	---	---	---	---	---
Bass River	43.5	20.6	22.9	---	---	22.9	0.0	---
Wading River	45.7	21.6	24.1	21.8	---	---	- 2.3	---
West Branch Wading River	45.7	21.6	24.1	24.1	---	---	0.0	---
Oswego Creek	41.8	21.4	24.4	18.7	---	---	- 5.7	-364.8
Batsto River	44.6	21.6	22.9	24.3	---	---	+ 1.4	+ 98.7
Atsion-Mechesactauxin Creek	44.2	21.9	22.3	23.6	---	---	+ 1.3	+115.4
Nescochaque Creek	44.4	22.1	22.3	---	---	22.3	0.0	---
Hammonton Creek	44.8	21.8	23.0	---	---	23.0	0.0	---
Mullica River	44.1	21.0	23.1	---	---	23.1	0.0	---
Great Egg Harbor Basin	44.4	22.0	22.4	---	---	---	---	---
Upper Great Egg Harbor	44.6	22.4	22.2	20.9	---	---	- 1.3	-221
Lower Great Egg Harbor	44.7	21.4	23.3	---	---	23.3	0.0	---
Maurice River Basin	42.8	22.8	20.0	---	---	---	---	---
Manumuskin Creek	43.0	22.8	20.2	---	---	20.2	0.0	---
Maurice River	42.5	23.0	19.5	20.2***	19.5	---	0.0	---
Absecon River	43.0	20.7	22.3	22.0***	22.3	---	0.0	---
Tuckahoe River	44.3	21.9	22.4	18.1	---	---	- 4.3	---
Dennis Creek	42.4	22.5	19.9	---	---	19.9	0.0	---
Patcong Creek	41.3	20.8	20.5	---	---	20.5	0.0	---

* Use the runoff value furthest to the right for budget computation.

** Attributable to basin transfer except at Tuckahoe River.

*** Gaga significantly upstream of basin outlet - flow adjusted to represent entire basin.

It is probable that all of the excess in the Forked River Basin (43.1 + 207 + 100 + 52.8 = + 403) comes from Oswego Creek (-365). Although the mass balance does not work out precisely, it is considered to be close enough to satisfy this premise.

The excess in the Atsion-Mechesactauxin Creeks probably comes from the Upper Great Egg drainage basin. The magnitude of the differences (+115 versus -221) indicates that basin transfer cannot account for all of the shortage in the Upper Great Egg Basin. It is likely that the remaining volume may be transferred to the Nescochaque Creek, although a basis to quantify this is unavailable.

Transfer anticipated from. the South Branch Rancocas. (-123) into the Batsto River (+99) is also considered probable. There is one very large discrepancy for the Tuckahoe River Basin which cannot reasonably be accounted for by basin transfer via the groundwater table slope theory discussed earlier. It is expected that this difference is due to either insufficient streamflow record, intra-basin transfer, streamflow gaging error or a precipitation measurement error, with the first being the most likely, Although an adjustment factor was used to extend the eight years of record to represent a longer period, it is not possible to be certain that the proper adjustment was made.

<u>Direct Runoff</u>

Total runoff from precipitation may be divided into four component parts: channel precipitation, overland flow, interflow and groundwater flow. Oirect precipitation onto water surfaces of streams, lakes and reservoirs makes an immediate contribution to streamflow and storm runoff. Overland flow is water which, failing to infiltrate the surface, flows over the ground surface towards a stream channel either as quasi-laminar sheet flow or as flow anastomosing in small trickles or minor rivulets. Interflow is water which infiltrates the soil surface and then moves laterally through the upper soil surface towards a stream channel. Groundwater flow is composed of precipitation which percolates through the soil and then moves laterally through the zone of saturation to stream channels.

Oirect runoff, or quickflow, is the sum of channel precipitation, surface runoff and rapid interflow, and represents the major runoff contribution during and shortly after storm periods. Baseflow is the sustained or fair-weather runoff and is the sum of the groundwater runoff and delayed interflow. In urbanized areas, flows into streams from storm sewers are also considered to be direct runoff.

In the Pinelands, heavy rainfall events usually result in fair- to well-defined increases in streamflow. As a result, storm periods appear as rises on the hydrographs of streams and make it possible to roughly separate runoff into its two major components, direct runoff and base-flow, using hydrograph separation. For example, the hydrograph for Westecunk Creek at the streamflow gaging station for the period May 20, 1973 to June 2, 1978 is plotted in Figure 12. Direct runoff (shaded area) from the estimated 4.3 inches of rainfall is 0.26 inches of run-off, only 6.2% of the rainfall.

The ratio of direct runoff to precipitation on the drainage area rises moderately with increasing precipitation. Figure 13 indicates that for Westecunk Creek direct runoff is about five percent for a two-inch storm and nine percent for a four-inch storm. The scatter of points in Figure 13 indicates that runoff response will not necessarily be uniform for storms with the same amount of rainfall.

Soil characteristics, water table depth, ground slope and volume of precipitation are the principal factors affecting direct runoff. These factors vary geographically, annually and seasonally. Not all portions of a drainage basin are effective in producing direct runoff. In general, "effective" areas are areas of standing or moving water and permanently or seasonally saturated soils and impervious surfaces connected* to stream channels and .adjacent flood plain areas. Watersheds with the higher precentages of land of this type will prcduce a greater unit volume of direct runoff than areas wfth a low percentage.

Direct runoff rates vary considerably between Pinelands drainage basins. Hydrograph separatfon analyses of three Pinelands watersheds--McDonalds Branch in Lebanon State Forest, Westecunk Creek at Stafford Forge and the Tuckahoe Creek at Head of River--revealed that the expected percentage of direct runoff from a four-inch storm during average watershed conditions ranges between 2.1 and 6.5 percent. This range of runoff rate is probably a result of a variability in the percentage of "effective" or "partial" areas between watersheds. Although no effective area maps are available for Pinelands watersheds, the hydrologic characteristics of Pinelands soils would appear to be a potential substitute.

The Soil Conservation Service (USDA-SCS) has developed a four-group hydrologic classification of the more than 4,000 soils in the United States. The basts for the four groups are:

1. The infiltration rate - the rate at which water enters the soil at the surface and which is controlled by surface conditions

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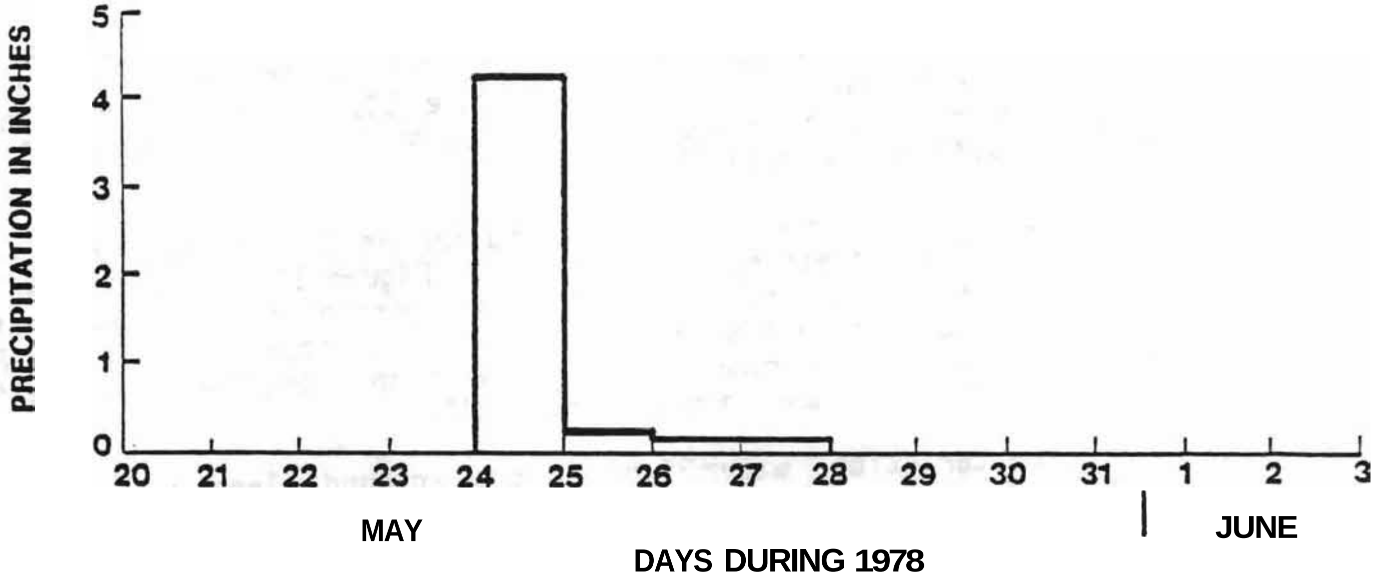
Source: USGS. 1979; NOAA. 1979
BCM Analysis



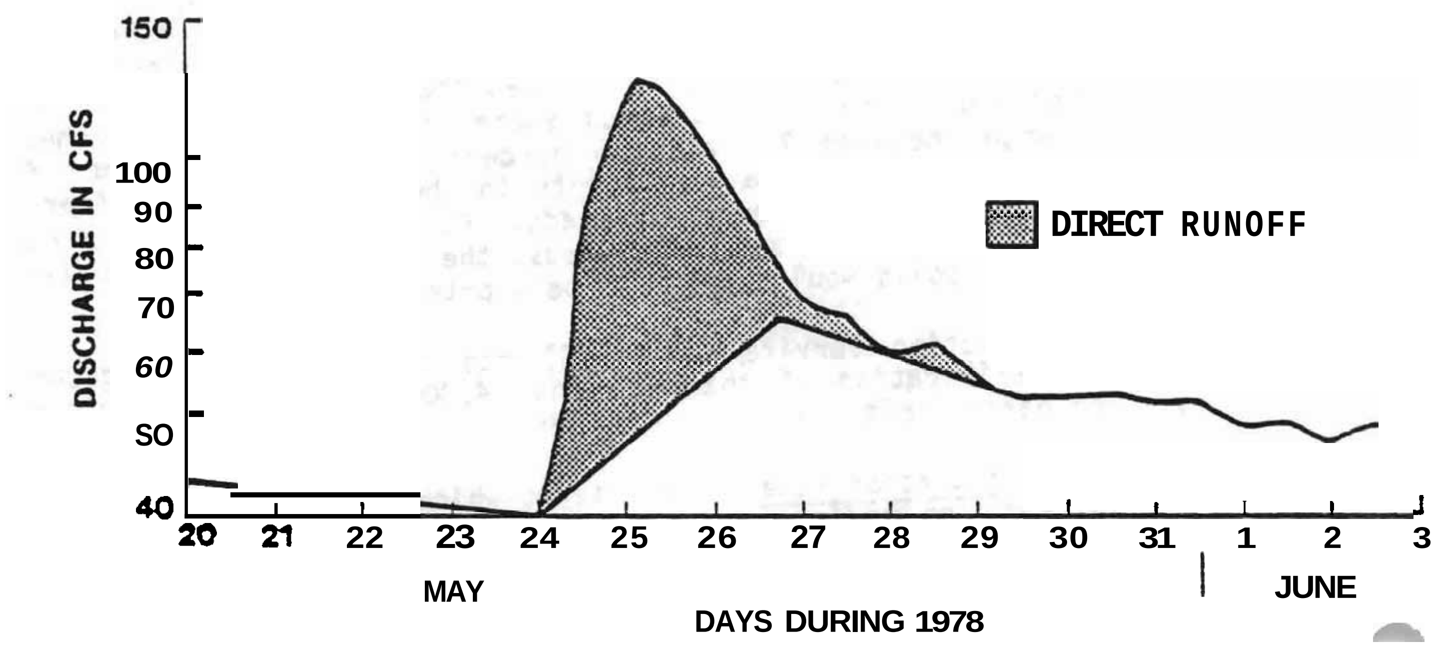


Figure 12 HYDROGRAPH FOR WESTECUNK CREEK AT STRAFFORD FORGE AND DAILY PRECIPITATION AT TUCKERTON

Betz • Converse • Murdoch • Inc.

Source: Data-USGS, 1979; NOAA, 1979, 1978
BCM Analysis

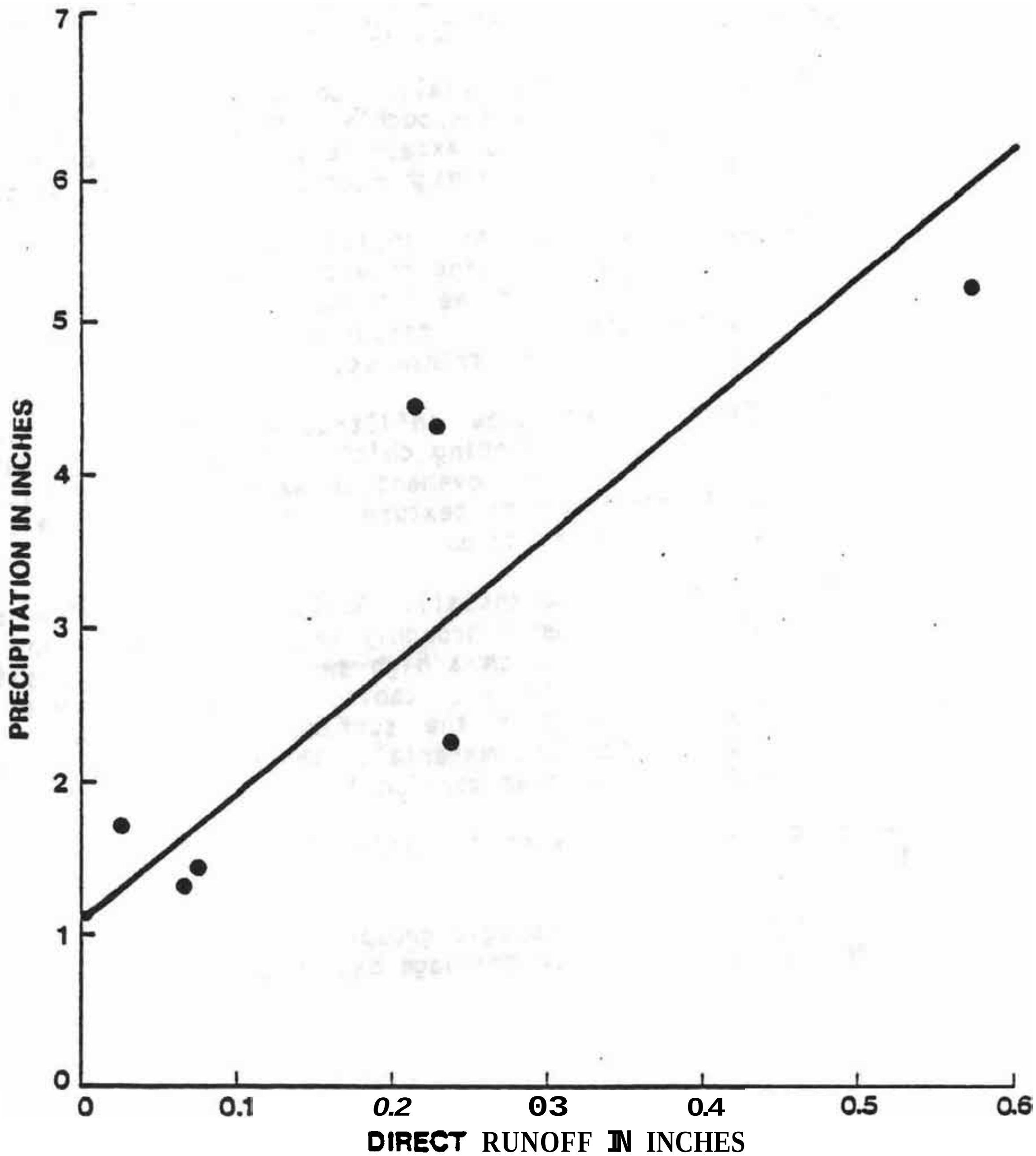


Figure 13. INCHES OF PRECIPITATION VS. INCHES OF DIRECT RUNOFF, WESTECUNK CREEK

2. The transmission rate - the rate at which the water moves through the soil ana which is controlled by the characteristics of the soil horizons

The hydrologic soil groups are defined as (SCS National Engineering Handbook, Section 4, Hydrology, 1972):

"A. (Low runoff potential). Soils havfng high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a hfgh rate of water transmission.

"B. Soils have moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

"C. Soils having slow infiltration rates when thoroughly wetted and consfstfng chfefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture, These soils have a slow rate of water transmission. .

"D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission."

Hydrologic soils groups of the major Pinelands are presented in Table 10.

Distribution of the hydrologic groups in the McDonalds Branch, Tuckahoe River and Westecunk Creek drainage basfns are shown fn Table 11.

TABLE 10

HYDROLOGIC SOILS GROUPS OF MAJOR PINELANDS SOIL SERIES

Soil Series	Hydrologic Soil Group*	Percent of Pinelands**
Lakewood	A	12
Evesboro	A	9
Fort Mott	A	< 1
Lakehurst	A	11
Total Percent of "A" Soils		32
Woodmansie	B	4
Downer	B	17
Sassafras	B	3
Aura	B	5
Klej	B	3
Total Percent of "B" Soils		32
Hammonton	C	4
Woodstown	C	< 0.5
Atsion	C	12
Marlton	C	< 0.5
Total Percent of "C" Soils		17
Fallsington	D	< 0.5
Berryland	D	4
Pocomoke	D	2
Muck	D	10
Alluvial land	D	--
Total Percent of "D" Soils		16

Source:

* USDA, SCS National Engineering Handbook, Vol. 4, Hydrology, 1972

** Marco L. Markley, Soil Series of the Pine Barrens: Pine Barrens Ecosystem and Landscape, 1979

TABLE 11

DISTRIBUTION OF HYDROLOGIC SOIL GROUPS
IN THREE PINELANDS DRAINAGE BASINS

		Soil Groups							
		A		B		C		D	
Drainage Basin	Drainage Area (square mile)	square mile	percent	square mile	percent	square mile	percent	square mile	percent
McDonalds Branch	2.67	2.07	77.6	0.31	11.7	0.22	8.3	0.7	2.5
Tuckahoe River	30.76	0.72	2.3	18.09	58.8	7.51	24.4	4.44	14.5
Westecunk Creek	15.72	10.23	65.0	1.98	13.0	1.11	7.0	2.4	15.72

A comparison of the soils groups distribution in Table 11 would suggest that the direct runoff response in McDonalds Branch, because of its low percentage of D soils (those soils with the highest runoff potential), is considerably smaller than the percentage of D soils in the other basins. This hypothesis is tentatively borne out in Figure 14, a plot of direct runoff from 2- and 4-inch storms versus percentage of D soils. The percentage of rainfall as direct runoff for McDonalds Branch (2.5% D soils) is approximately two percent, while the percentage of rainfall as direct runoff for the other two baslns (15% D soils) is approximately five to six percent. Although analyses of more storms* and more watersheds are necessary before a more reliable relationship can be obtained, it is apparent that the higher the precent of D soils in a watershed, the greater the direct runoff and, as a result, the lesser the amount of recharge to the groundwater system. Observation of the distribution of the soils groups on the soils map of the Cooks Branch drainage basin, a tributary to Cedar Creek basin (Figure 15), identifies another important characteristic of D soils and, to a lesser extent, C soils.

All areas of D and most areas of C soils are contiguous to stream channels. As described earlier, for direct runoff to occur from a piece of ground, a direct saturated connection to a stream channel is required. In general; D and C, but not A and B, soils have this connection.

In addition to using two SCS hydrologic groups as an alternative to an "effective" area map, a preliminary analysis was made to see whether the runoff volumes determined by hydrograph analysis were roughly equivalent to the runoff volumes predicted by the SCS's Soil Cover Complex Method (USDA-SCS, 1972).

The estimated volumes of runoff for two watersheds for a 4-inch storm were compared to the volume predicted using SCS's methodology. Two alternative "effective" direct runoff source areas were investigated. In the first set of watershed analyses, it was assumed that D soils were

---

* Eight storm discharge hydrographs from each gage were separated into direct and base runoff components. The volume of direct runoff was obtained by measuring the area within the direct runoff component and converting the area value into inches of runoff over the entire drainage basin upstream from the gage. Precipitation is not measured in the basins. Precipitation amounts were synthesized from nearby precipitation stations, thus adding an unknown degree of uncertainty to the rainfall data used in the analysis.

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Source: BCM

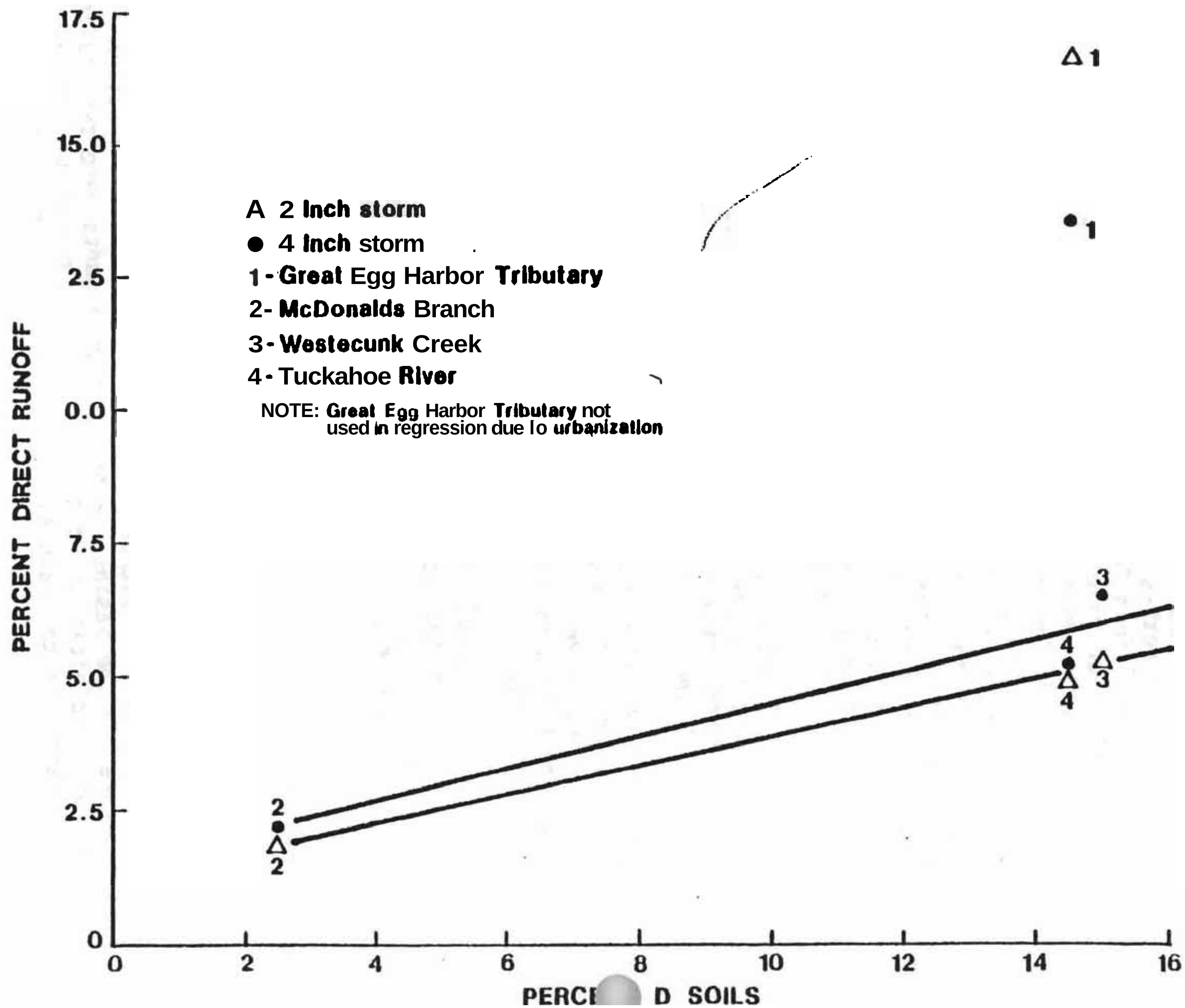

Figure 14 PERCENTAGE OF DIRECT RUNOFF VS. PERCENTAGE OF D SOILS

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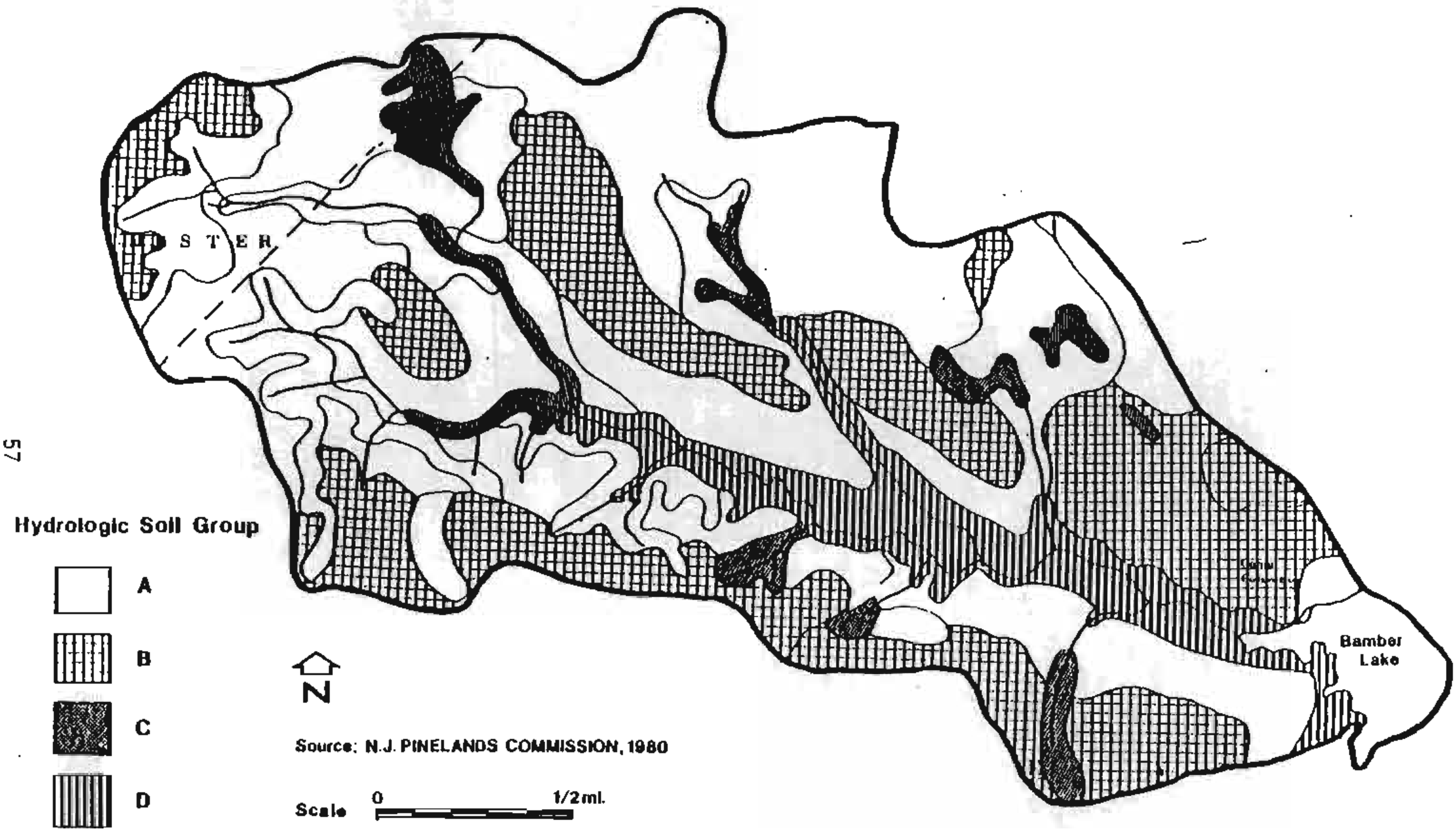

Figure 15. DISTRIBUTION OF HYDROLOGIC SOIL GROUPS, COOKS BRANCH, CEDAR CREEK DRAINAGE BASIN

the sole source of direct runoff and in the second, it was assumed that both 3 and C soils contributed to the direct runoff. The data used and results of the analysis are presented in Table 12.

The analyses proved inconclusive. If D soils are the sole source of direct runoff, the Soil Cover Complex Method does an adequate job for Westecunk Creek (1.8 inches predicted, 1.66 inches estimated empirically), but is far off For McDonalds Branch (1.8 inches predicted, 3.36 inches estimated). Use of D and C soils does not improve the estimates. The variance in results may be due to an insufficient data base to estimate the rainfall runoff relationships in the watersheds and/or an inaccuracy in the SCS methods in predicting runoff in the Pinelands. Because the data used to develop the rainfall-runoff relationship are few and because the rainfall data were obtained indirectly, it is highly likely that this is a contributing factor. It is recommended that additional investigation of the rainfall-runoff relationship in the Pinelands be conducted.

Rhodehamel (1970) estimated that direct runoff in the Mullica River Basin constituted 11% of total runoff. His estimate was based on the assumption that riparian lands (areas of saturated soil and water bodies) which compose approximately 15% of the basin were the source of direct runoff and the majority of direct runoff occurs between December and April when soil moisture levels and water tables are high. During these five months, the Pinelands normally receives about 17.25 inches of precipitation. Because evapotranspiration losses are very small during these months, most of the precipitation becomes direct runoff. The average runoff, therefore, would be 2.5 inches, or 11% of the total 22.5 inches calculated by Rhodehamel. Basins with less riparian land would have a smaller percent of direct runoff. No analysis or' total direct runoff or total recharge of the groundwater reservoir was conducted as a part of the current study.

Relationship Between Groundwater Levels and Surface Water Flow

The ultimate source of all groundwater in the Pinelands area is precipitation that 'infiltrates downward through the soil zone and the zone of aeration to the water table. Fluctuations of the water table indicate relative rates of recharge to or discharge from the groundwater reservoir. When recharge exceeds discharge, water levels rise; conversely, when recharge is less than discharge, water levels decline. The three factors influencing recharge and discharge are precipitation, evapotranspiration, and streamflow. Typically, monthly recharge exceeds discharge during the winter and early spring. Discharge exceeds recharge

TABLE 12

COMPARISON OF ESTIMATED AND PREDICTED DIRECT RUNOFF AMOUNTS

Stream Name	Total Area (Square Miles)	D Soils In Basin (Percent)	D + C Soils In Basin (Percent)	Estimated Basin Runoff from 4-Inch Storm* (Inches)	Estimated or Predicted Direct Runoff Amounts (Inches): D Soils "Effective" Source Area — Hydrograph Separation	D Soils "Effective" Source Area — Soil Cover Complex Method	D&C Soils "Effective" Source Area — Hydrograph Separation	D&C Soils "Effective" Source Area — Soil Cover Complex Method
McDonalds Branch	2.67	2.5	10.5	0.084	3.36	1.8	0.77	1.4
Westecunk Creek	15.72	15	22	0.26	1.66	1.8	1.15	1.1

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during the summer and fall. Atypical levels may result, especially during periods of prolonged drought or heavy rains. Monthly groundwater levels in the Mount well near Batsto are plotted in Figure 16.

As described in the section on direct runoff, approximately 90% of total streamflow in the Pinelands is base flow. The majority of this flow is groundwater discharge. As a result, streamflow in Pinelands streams is largely a function of water table levels.

Figure 17 presents a plot of the lowest daily water level of Well 18-V in the Lebanon State Forest and average daily streamflow at the McDonalds Branch streamflow gage. Because the well and stream gage are less than four miles apart, the drainage basin characteristfcs, including topography, soils, vegetation, and land use are similar, and the elevation of the average water table and stream stage are within 10 feet of each other, the water table fluctuations at Well 18-V are representative of water table fluctuations in the McDonalds Branch basin. The close relationship between water table and streamflow fluctuations is clearly indicated by the plots. This relationship is also indicated by the plot of discharge versus elevation of the water table.

Close relationships between water table elevations and groundwater discharge to surface streams should resemble the relationships shown in Figure 18. On the larger streams, there is likely to be a two- to three-day lag between fluctuations in water table and streamflaw. Technical memorandum GW-II should be consulted for additional information on the groundwater hydrology of the Pinelands.

DYNAMICS OF THE FRESHWATER-SALTWATER INTERFACE

The aquatic ecology of the estuaries downstream from Pinelands streams is partially a function of the quantity and distribution of fresh water delivered to the estuaries and the resulting estuarine salinity levels. As described in Technical Memorandum SW IV-3, the life cycles and health of estuarine organisms (some of which are economically important, such as oysters, or are part of the food chain on which economically important species are dependent) depend upon certain salinity levels. Low salinity portions of the estuary serve as a spawning and breeding ground for many marine organisms. The low salinity ensures that the young and the larvae are separated from more mature stages and predators.

The objective of this section is to present available information that describes the relationship between streamflow and estuarine salinity levels. The only Pinelands estuarine system which has been studied in

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Source: Rhodehamel, 1973

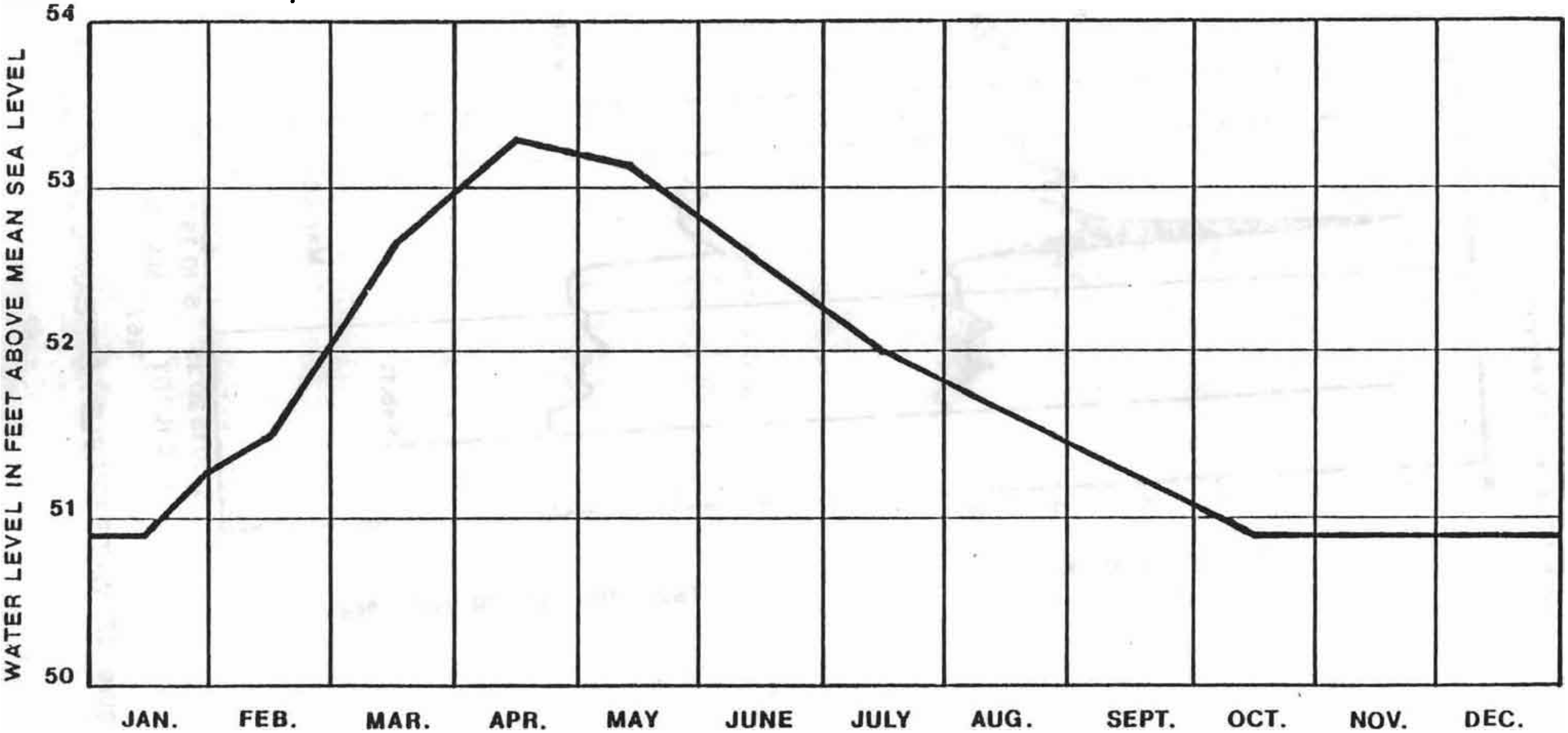

Figure 16. MONTHLY GROUNDWATER LEVEL IN THE MOUNT WELL, 1956-68

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Source: USGS, 1979: BCM Analysis

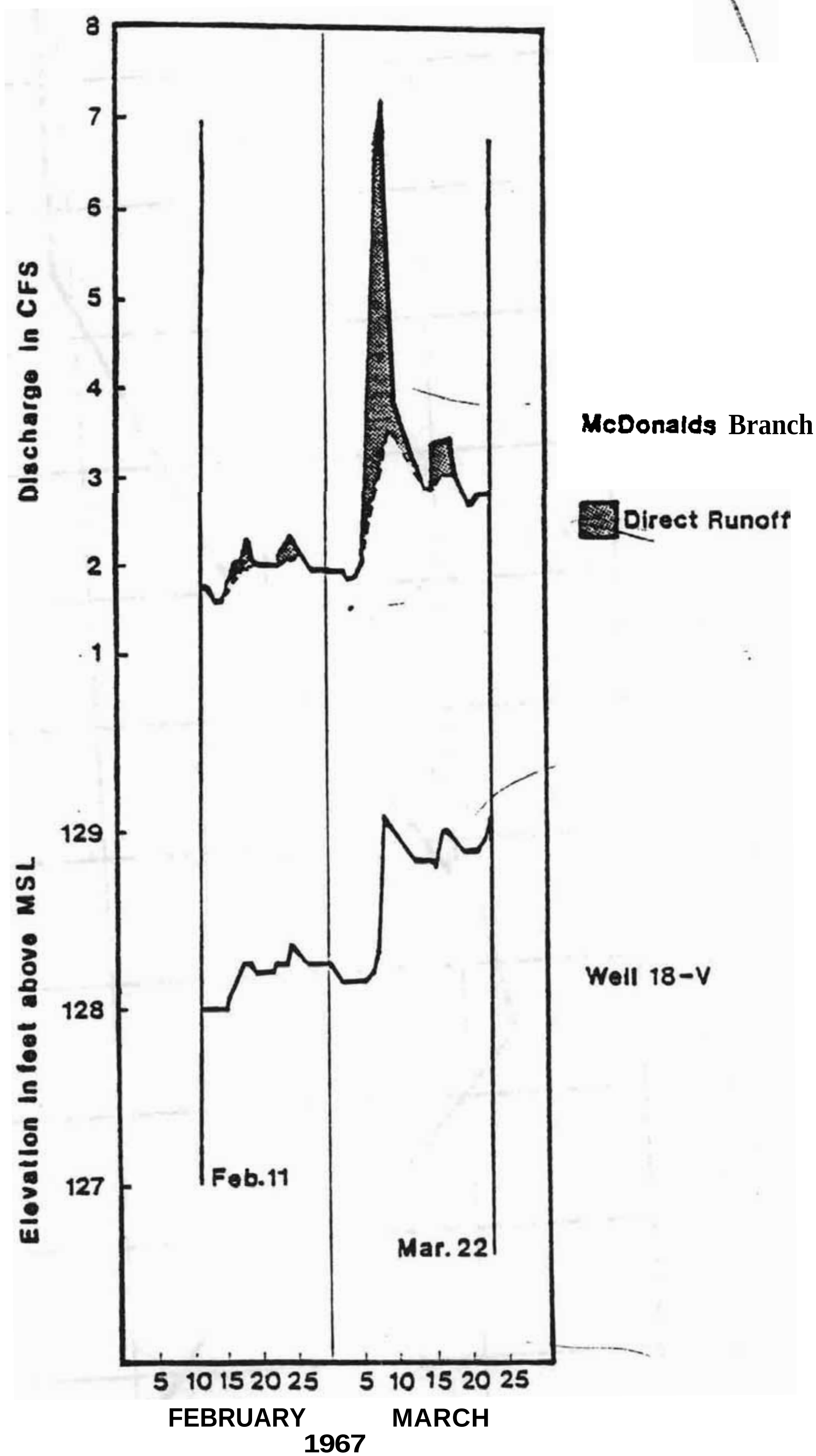

Figure 17. WATER TABLE / STREAMFLOW FLUCTUATIONS

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Source: USGS, 1979; BCM Analysis

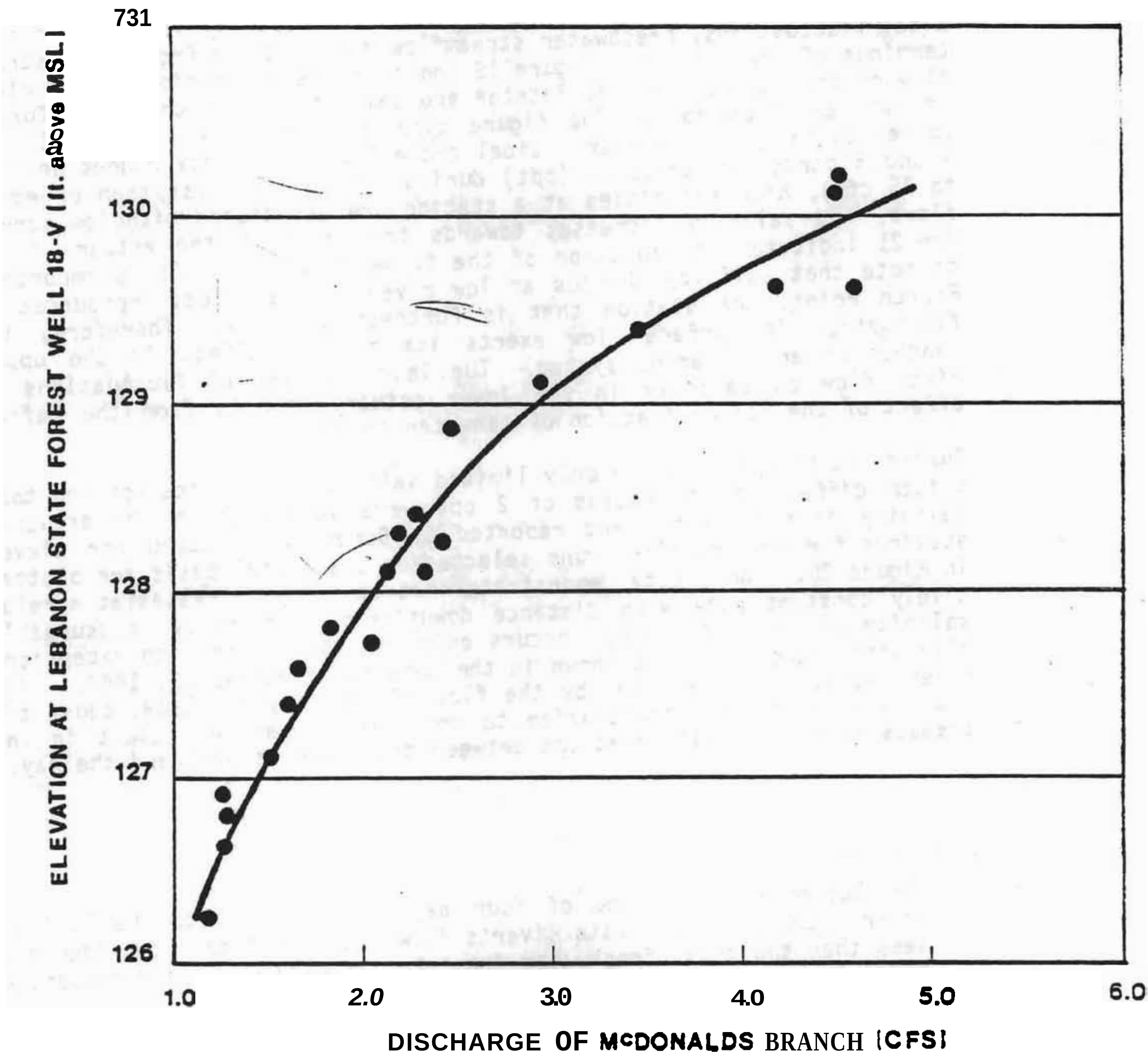

Figure 18. WATER TABLE / STREAMFLOW RELATIONSHIP

detail is the Mullica River estuary (Durand and Nadeau, 1972). A summary of the results of that study is presented in the following paragraphs. Recommended maximum mean manthly low water salinities and corresponding streamflows were established by Durand and Nadeau. Their recommendations and the abf1fty to extrapolate this information to other estuaries are also disassed.

Salfnity at any location in the Mullica River estuary fs a function of tidal fluctuations, freshwater streamflow and distance from the upstream terminus of the estuary. Figure 19 shows the relationship between river flow of the Batsto River at Batsto* and salinity at French Point, Turtle Island, and Cape Horn. The figure displays the three elements listed above; salinity varies over a tidal cycle (e.g., salfnfty ranges between 4 and 5 parts per thousand (ppt) during streamflows less than or equal to 75 cfs), high salinities at a statfon are associated with low stream flows, and salfnity increases towards the mouth of the estuary (Figure 21 indfcates the location of the three stations). It fs important to note that salinity changes at low river flow are most pronounced at French Point, the station that is furthest upstream. Therefore, any fluctuation in surface flow exerts its maximum effect in the upper reaches of an estuarine system. The lesser effect of fluctuations in river flow on salinfty In the lower estuary results from the buffer effect of the larger fraction of seawater there.

Durand and Nadeau reported only limited salinity stratification (no top-bottom differences in excess of 2 ppt were observed) in the estuary. Salinity data collected and reported by Durand and Nadeau for eleven stations for four sampling runs selected on a seasonal basis are plotted in Figure 20. These data demonstrate that salinity increases at a relatively constant rate with distance downstream. Generally, measureable salinity between R14 and RL7 occurs only in association wfth exceptionally high tides. This is shown in the data for November 18, 1968. High river Plows, as represented by the flow of February 27, 1969, cause the upper limits of salt penetration to move downstream and result in increases in the salinity gradient between the upper estuary and the bay.

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* The Batsto Rfver is one of four major tributaries to the Mullica River estuary. The Batsto River's flow rates, although considerably less than the total freshwater input to the estuary, are representative of the flow regime of the major freshwater streams.

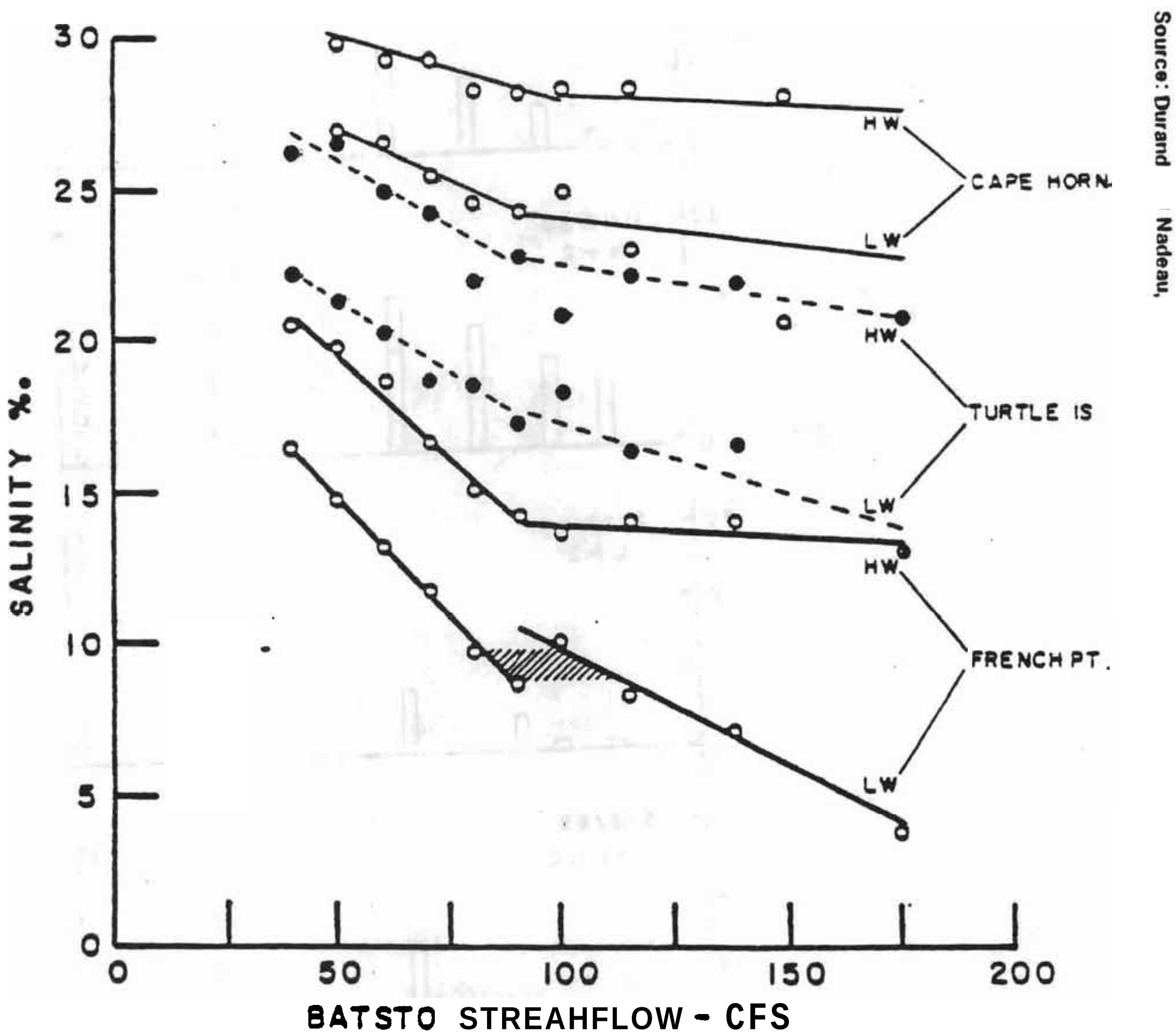
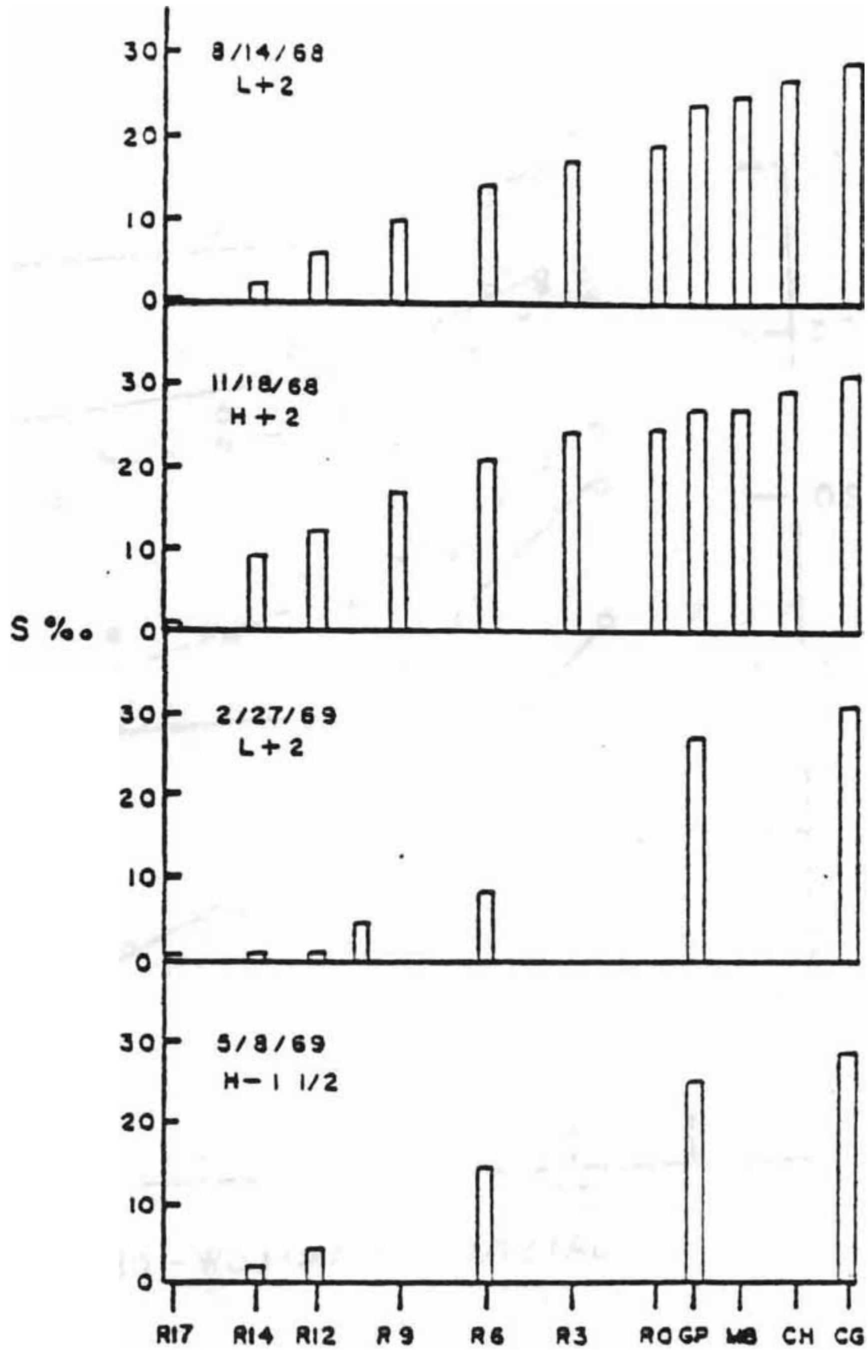


Figure 19 RELATIONSHIP BETWEEN SURFACE SALINITY AT FRENCH POINT, TURTLE ISLAND AND CAPE HORN IN THE MULLICA RIVER AND STREAMFLOW AS GAGED AT THE BATSTO RIVER, GAGING STATION



Source: Durand and Nadeau, 1972

Figure 20, SALINITY AT INDICATED STATIONS AS MEASURED ON UP RIVER RUNS DURING SUMMER*FALL WINTER, AND SPRING OF 1968 AND 1969

Figures under the dates indicate hours before or after high or low water.

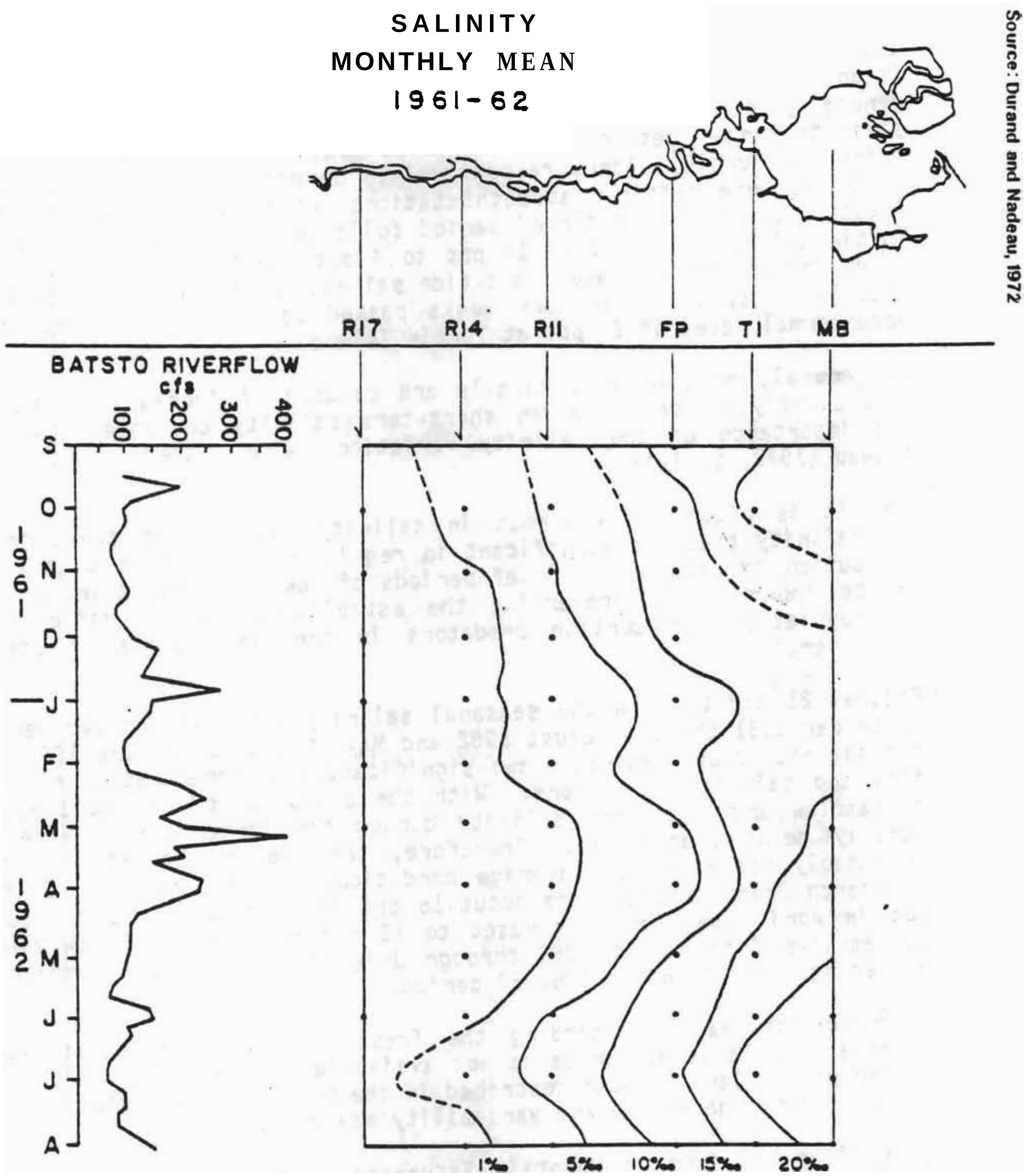


Figure 21. SALINITY MEASUREMENTS CONTOURED FOR THE MULLICA RNER AND GREAT BAY, 1961-1962

Monthly means of measurement plotted. Measurements made approximately weekly during fall, winter and spring; more often in the summer. The Batsto river during this period approximated the 38-year mean flow. Dots represent position of monthly mean data points.

Extreme low salinities can occur as far down the estuary as Turtle Island following heavy precipitation events superimposed on periods of generally high precipitation and streamflow. Mean summer low tide salinity ranges between about 9 to 11 ppt, and 18 to 20 ppt at French Point and Turtle Island, respectively. On occasion, salinities as low as 3 ppt were measured at both stations during high flows in July and August. During one recorded period following heavy rains, salinity at Turtle Island dropped from 17 ppt to 4 ppt (measured near mid-tide) in three days. Within a week, mid-tide salinities had increased to approximately 13 ppt. A few more weeks passed before salinity reached the more normal level of 20 ppt at Turtle Island.

In general, most heavy rainfalls are capable of increasing streamflow sufficiently to cause sudden short-term salinity decreases downriver. The importance of the salinity variations were stated by Durand and Nadeau (1972, p. 11):

> "It is often the extremes in salinity rather than the mean salinity that are significant in regulating population distribution in estuaries. Brief periods of low salinity, then, may be important in preventing the establishment of significant populations of certain predators in the lower parts of the river."

Figures 21 and 22 show the seasonal salinity patterns for two periods, September 1961 through August 1962 and May 1968 through June 1969. The two salinity plats represent two significantly different sets of streamflow and salinity conditions, With the exception of August 1962, the streamflow and resultant salinity during the former period were near monthly means (Table 13). Therefore, the 1961-62 salinity patterns presumably represent the average conditions of the estuary. Salinity at French Point dropped from about 15 ppt in September 1961 to about 4 ppt in April 1962, and increased to 12 ppt by August. Below average streamflows from August 1968 through June 1969 (Table 13) resulted in higher salinity than the 1961-62 period.

In-depth information regarding the freshwator-saltwatcr relationships in other Pinelands estuaries is not available. It is likely that relationships similar to those described in the Mullica River estuary exist, although their magnitude and variability may differ.

<u>Base Flows Required to Maintain Estuarine Freshwater-Saltwater Interfaces</u>

As described in the preceding section, the salinity of an estuary and the estuarine freshwater-saltwater relationships are dynamic, not

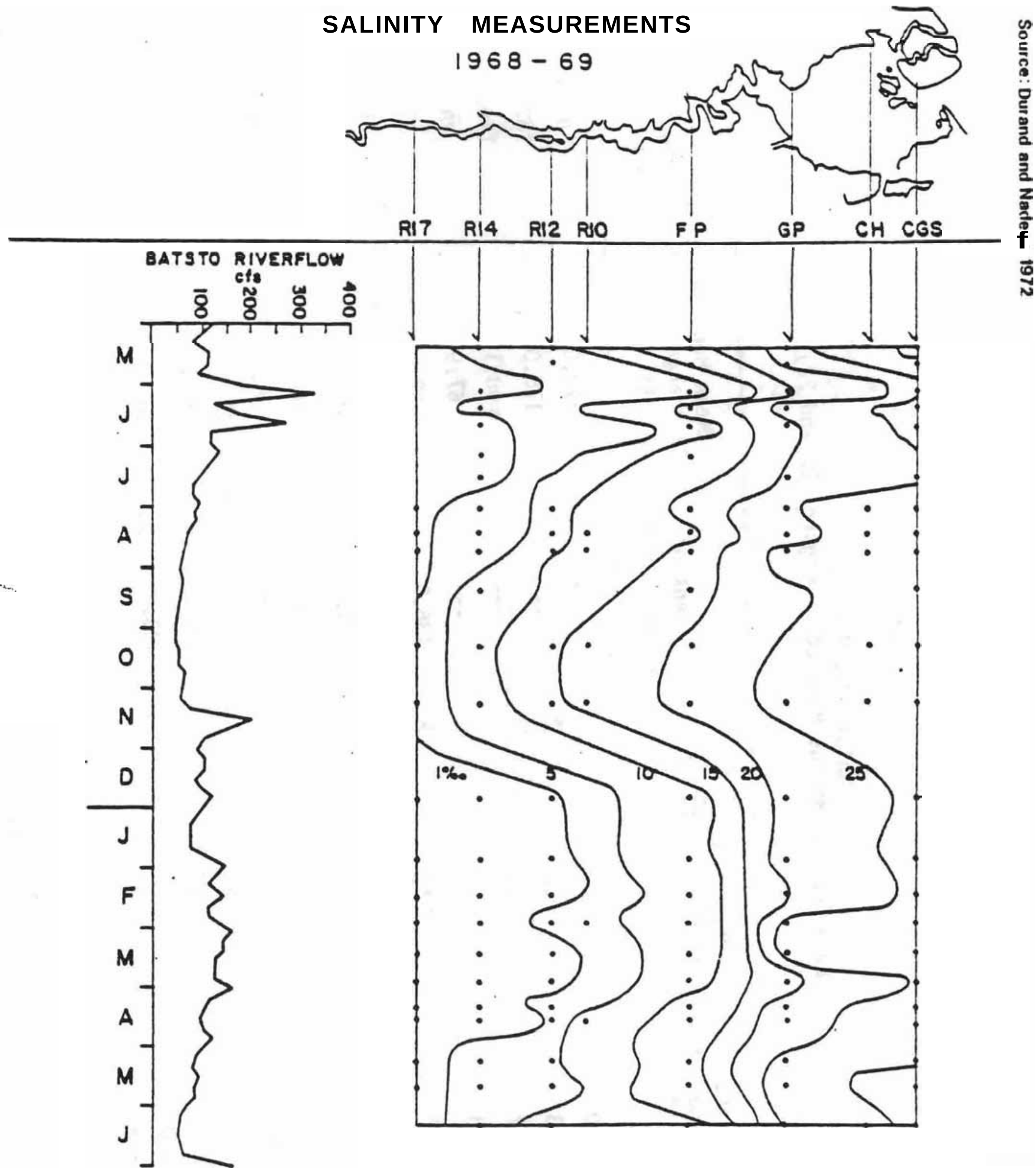


Figure 22, SALINITY MEASUREMENTS CONTOURED FOR THE MULLICA RIVER AND GREAT BAY, 1968-1969

Individual salinity measurements plotted. Dots represent position of data points. Late summer and early fall Batsto River flows were abnormally low during this period.

TABLE 13

BATSTO RIVER FLOW
(Data for the Months Plotted In Figures 21 and 22)

Month	Mean Monthly Discharge (cfs) 39-year Median	Mean Monthly Discharge 1961-62 (cfs)	Percent of 39-year Median	Mean Monthly Discharge 1968-69 (cfs)	Percent of 39-year Median
May	131.0	---	---	123.0	94.0
June	96.3	---	---	175.0	182.0
July	84.7	---	---	98.1	116.0
August	86.8	---	---	67.9	78.0
September	73.5	99.6	136.0	52.6	72.0
October	75.6	116.0	153.0	53.5	71.0
November	112.0	86.9	78.0	109.0	97.0
December	121.0	110.0	91.0	100.0	83.0
January	141.0	146.0	104.0	95.5	68.0
February	142.0	129.0	91.0	127.0	89.0
March	163.0	222.0	136.0	138.0	85.0
April	141.0	173.0	123.0	109.0	77.0
May	131.0	94.3	72.0	84.3	64.0
June	96.3	104.0	108.0	78.8	82.0
July	84.7	74.7	88.0	---	---
August	86.8	194.0	224.0	---	---

Source: U.S. Geological Survey
Analysis: Betz Converse Murdoch I[illegible]

static. Salinity at any given location at any point in time is a function of the following factors:

1. Freshwater streamflow into the estuary (varies daily, seasonally and annually)

2. Stage of the tidal cycle

3. Distance from the upstream terminous of the estuary

4. Estuarine hydraulics

As a result, because there are so many factors and because each estuarine system has its own characteristics of freshwater inflow, tidal fluctuation, length and shape, and circulation, it is extremely difficult to establish a complete understanding of a system where data are available, much less extrapolate information from one watershed to another. Also, as a result of these physical and other variations, including differences in substrates and marsh characteristics, the ecologic system and its requirements cannot be directly equated from one estuary to another. The only Pinelands river-estuarine system which has been studied in detail and for which data were available is the Mullica River.

Recommended maximum monthly Mullica River salinity levels and the freshwater streamflow necessary to maintain these levels were developed by Durand and Nadeau (1972, p. 68) as part of a project to evaluate the water resources development potential of the Mullica River Basin. The recommended salinities and associated streamflows are presentea in Table 14. The flows they present were selected to ensure that salinity levels would not become so high as to alter the existing ecology of the area (Durand and Nadeau, 1972, p. 44).

An analysis of mean monthly flow frequency of the Batsto Rfver For each month was made in order to establish whether there was a consistent pattern between the recommended Flows and the frequency at which they are obtained. Figure 23 displays the results of the flow frequency analysis for August. The average monthly flow recommended, 57 cfs, was equaled or exceeded in 78% of the Augusts during the 39-year period of record. Looking at it another way, the recommended flow was not obtained in 22% of the Augusts.

This type of freauency analysis can be used to estimate the likelihooa that specific flows, such as 57 cfs, will be eaualed or exceeded in any given year. As a result, assuming watershed hydrologic conditions remain relatively unchanged, there is a 22% chance that the flow during the month of Aupust of any given future year will be less than 57 cfs. Probabilities of the flows associated with the recommenced maximum monthly salinities not being obtained are presented in Table i4. The likelihood of nonattainment ranges from 7% in March to 47% in Gctober.

TABLE 14

MAXIMUM MEAN MONTHLY LOW WATER SALINITIES*
TO BE MAINTAINED AT FRENCH POINT IN THE MULLICA RIVER
AND THE CORRESPONDING BATSTO RIVER STREAMFLOW

(1) Month	(2) Salinity (Percent)	(3) Batsto Streamflow (cfs)	(4) Likelihood that Flow will not be Obtained in any Given Year* (Percent)
October	11.6	72	47
November	11.3	74	15
December	10.4	81	17
January	9.0	97	20
February	8.4	112	17
March	8.4	112	7
April	9.4	94	15
May	9.8	90	17
June	11.0	76	30
July	12.0	68	30
August	13.8	57	22
September	13.3	60	30

* Recommended by Durand and Nadeau, 1972

** Based on 39-year flow records (1940-1978). Columns 1, 2 and 3 from Durand and Nadeau (1972).

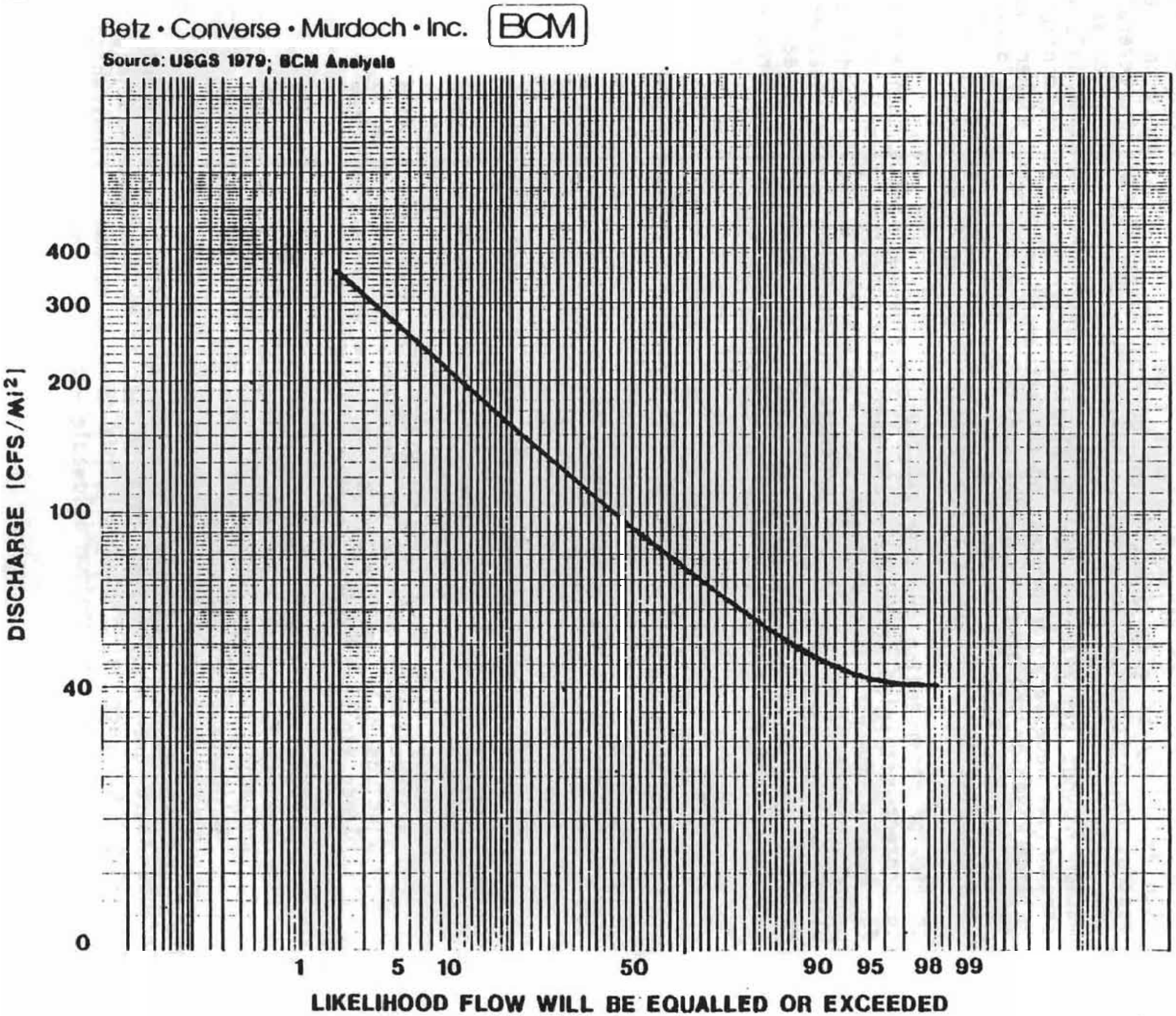


Figure 23. MEAN MONTHLY FLOW DURATION, AUGUST, BATSTO RIVER AT BATSTO

At the outset of the present investigation, it had been hoped that the information developed by Durand and Nadeau could be used to develop recommended minimum streamflows to maintain estuarine freshwater-saltwater equalibrium for other Pinelands streams. However, based on the high frequency of flow unattainment of the Batsto River for several months, and a conversation with Dr. Durand (oral communication, January 1980), it has been concluded that the Batsto River-Mullica River information is not satisfactory for developing recommendations on minimum streamflows necessary for protecting the estuarine ecology of either the Mullica River or the other estuaries within or downstream from the Pinelands National Reserve. Much more data are necessary before a full understanding of estuarine salinity relationships can be obtained.

In lieu of recommending specific streamflows which should be maintained to protect estuarine freshwater-saltwater relationships, monthly flows for each of the Pinelands drainage basins which have a 75, 90, and 98% probability of being equaled or exceeded in any given year, together with the likelihood of exceedance developed from Durand and Nadeau's Mullica River data, are presented in Appendix 2. The following procedures were used to develop the flows presented in Appendix 2:

1. Gaged watersheds with gage near basin mouth - monthly flow duration analyses were made from available flow data without adjustments

2. Gaged watersheds with streamflow sages located upstream from the mouth - monthly flow duration analyses were made; flow rates at the basin mouth were obtained by arithmetically adjusting flows to account for total drainage area.

3. Gaged watersheds with streamflow gaging stations located downstream from the Pinelands National Reserve Boundary - monthly flow duration analyses were maae; Flows were arithmetically adjusted on the basis of drainage area to include only the portion of drainage basin within Pinelands National Reserve boundary.

4. Ungaged watersheds - mean flows obtained from Table 2; monthly flows and flow durations were obtained by extrapolation from mean flow to 75, 90, 98% flow relationships at nearby gaged watersheds.

The flows presented in Appendix 2 have been provided for guidance only. Because there are insufficient data on estuarine freshwater-salinity relationships, there is no basis at this time to recommend flows which should be established as minimum allowable estuary inflow.

REFERENCES

Durand, J. B. Oral communication, 1980.

Durand, J. B. and R. J. Nadeau. Water Resources Development in the Mullica River Estuary, Part I, Biological Evaluation of the Mullica River-Great Bay Estuary, New Jersey Water Resources Research Institute, 1972.

Hely, A. G., J. J. Nordenson, and others. Precipitation, Water Loss and Runoff in the Delaware River Basin and New Jersey, U.S. Geological Survey, Hydrology Inventory Atlas HA-11, 1961.

Markley, M. L. Soil Series of the Pine Barrens, In: Pine Barrens Ecosystem and Landscape, R. T. Forman, Ed., 1979.

Rhodehamel, E. C. A Hydrologic Analysis of the New Jersey Pine Barrens Region, State of New Jersey Department of Environmental Protection, Division of Water Policy and Supply, Water Resources Circular No. 22, 1970.

Rhodehamel, E.C. Geology and Water Resources of the Wharton Tract and the Mullica River Basin in Southern New Jersey, State of New Jersey Department of Environmental Protection, Division of Water Resources, Special Report No. 36, 1973.

Robertson, D. K. Hydrologic Planning of the New Jersey Pine Barrens, In: Natural and Cultural Resources of the New Jersey Pinelands, 1978.

Thornthwatte, C. W. and J. R. Mather. The Water Budget and its Use in Irrigation, In: 1955 Yearbook of Agriculture, Water, U.S. Department of Agriculture, 1955.

U.S. Department of Agriculture, Soil Conservation Service. Interim Soil Survey, Ocean County, New Jersey, 1977.

U.S. Department of Agriculture, Soil Conservation Service. National Engineering Handbook, Vol. 4, Hydrology, 1972.

U.S. Department of Agriculture, Soil Conservation Service. Soil Survey, Burlington County, New Jersey, 1971.

U.S. Department of Agriculture, Soil Conservation Service. Soil Survey, Camden County, New Jersey, 1962.

U.S. Department of Commerce. Climatological Data far New Jersey, 1979.

U.S. Department of Commerce. Local Climatoligical Oata, Atlantic City, New Jersey, 1978.

U.S. Department of Commerce, Weather Bureau. Rainfall frequency Atlas of the United States, Technical Paper No. 40, 1961.

U.S. Department of the Interior. Geological survey, streamflow data and statistical analyses conducted at the request of Betz*Converse•Murdoch•Inc. (8CM), 1979.

U.S. Water Resources Council. Guidelines for Determining Flood Flow Frequency, Bulletin 17A, 1978.

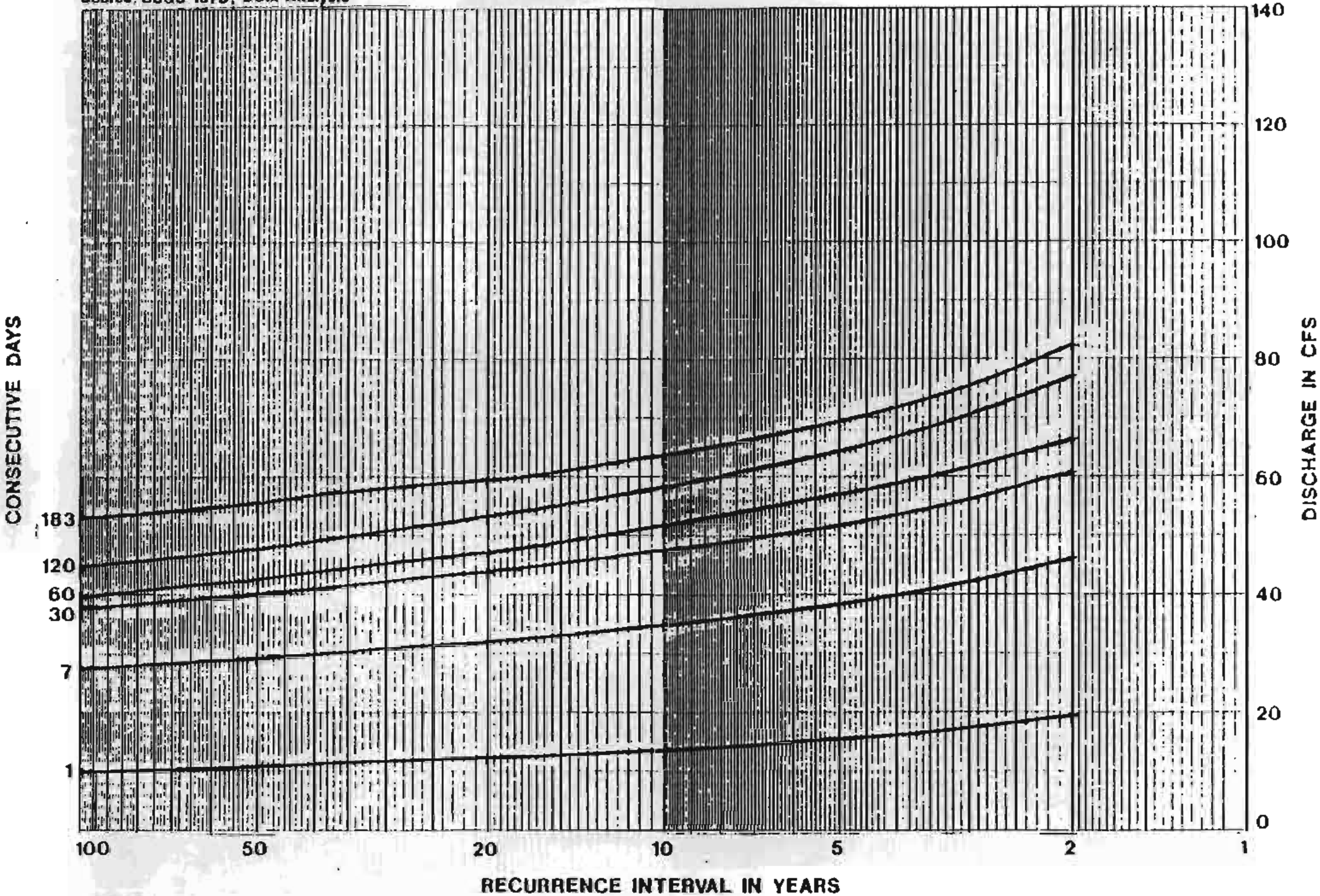
Ward, R. C. Principles of Hydrology, 1975.

APPENGIX 1

LOW FLOW FREQUENCY CURVES

Betz · Converse · Murdoch · Inc. BCM

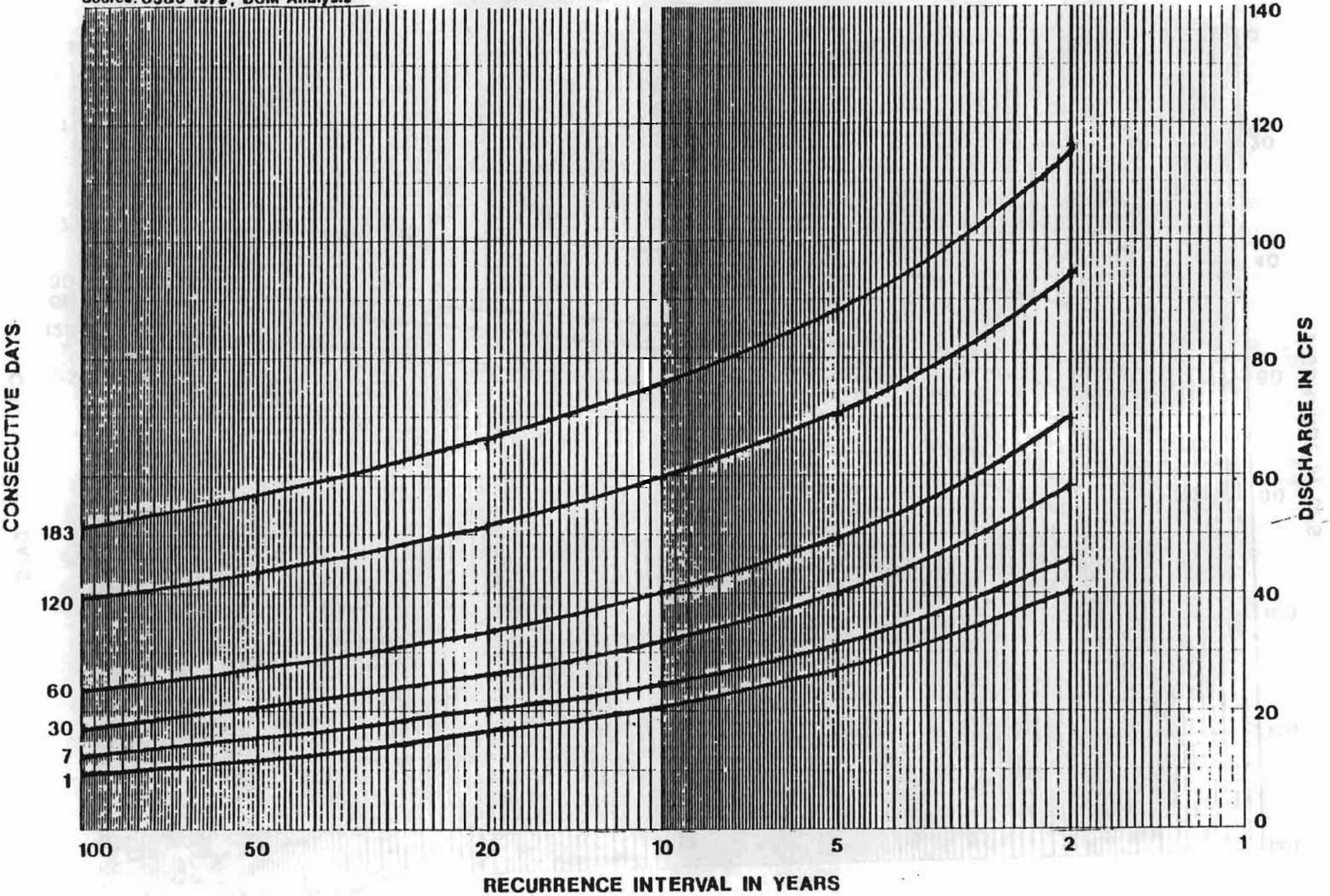
Source: USGS 1979; BCM Analysis



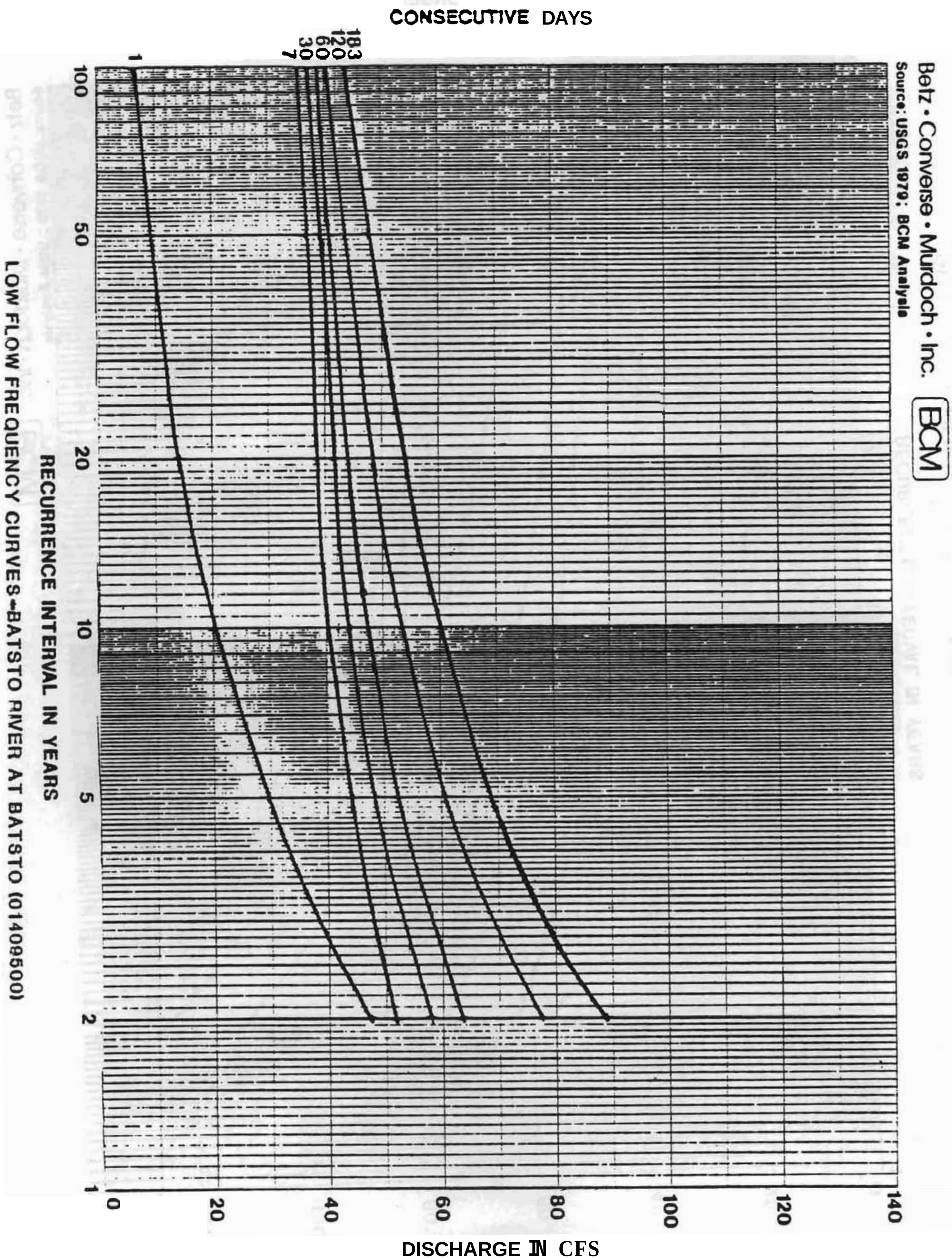
LOW FLOW FREQUENCY CURVES-CEDAR CREEK NEAR LAKODA (1409000)

Betz · Converse · Murdoch · Inc. BCM

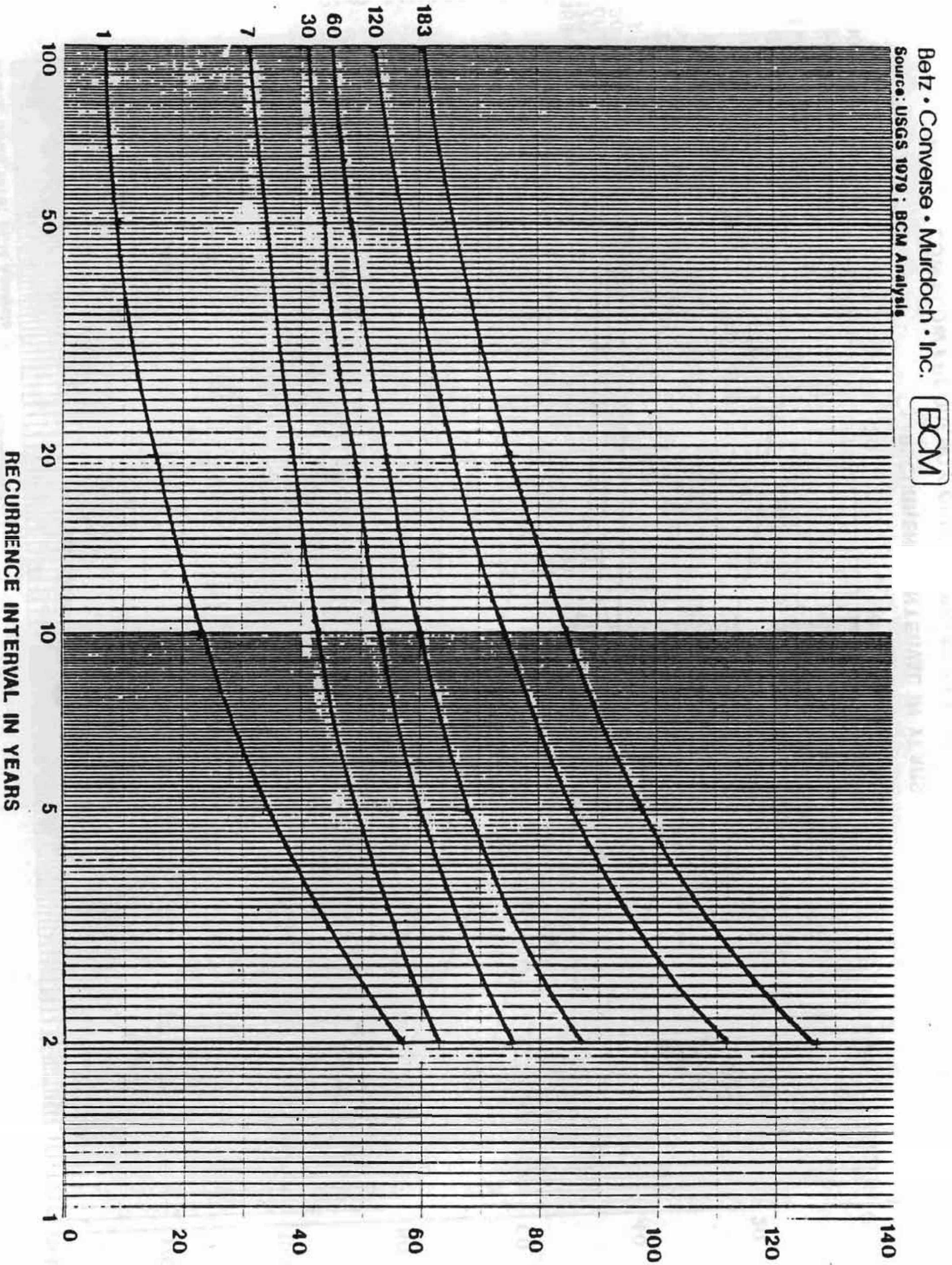
Source: USGS 1979; BCM Analysis



LOW FLOW FREQUENCY CURVES-TOMS RIVER (01408500)


CONSECUTIVE DAYS
183
120
60
30
7
1
Betz • Converse • Murdoch • Inc.
BCM
Source: USGS 1979; BCM Analysis
100
50
20
10
5
2
1
RECURRENCE INTERVAL IN YEARS
0
20
40
60
80
100
120
140
DISCHARGE IN CFS
LOW FLOW FREQUENCY CURVES--BATSTO RIVER AT BATSTO (01409500)

CONSECUTIVE DAYS

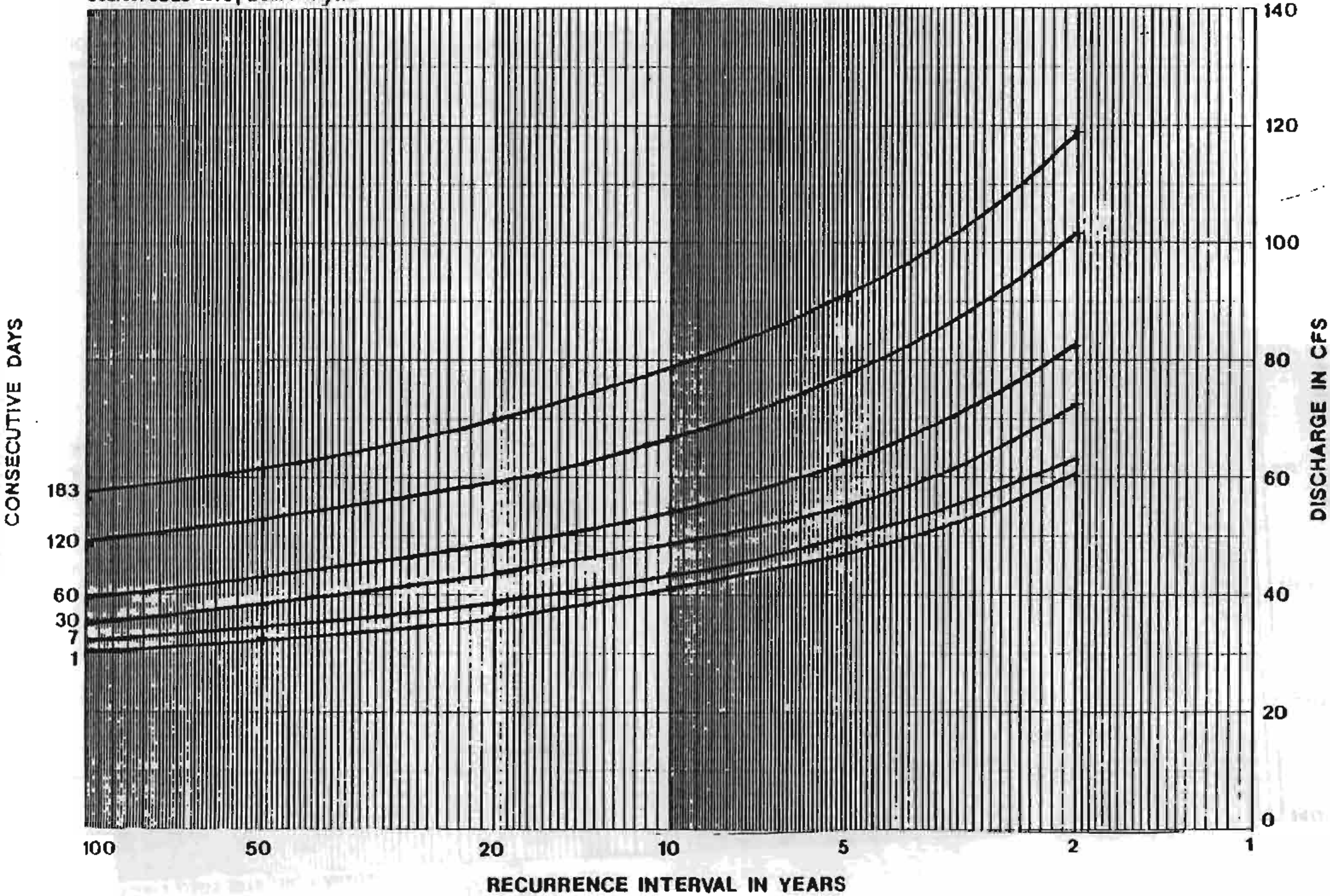


LOW FLOW FREQUENCY CURVES-OSWEGO CREEK AT HARRISVILLE (0141000)

DISCHARGE IN CFS

Betz • Converse • Murdoch • Inc. BCM

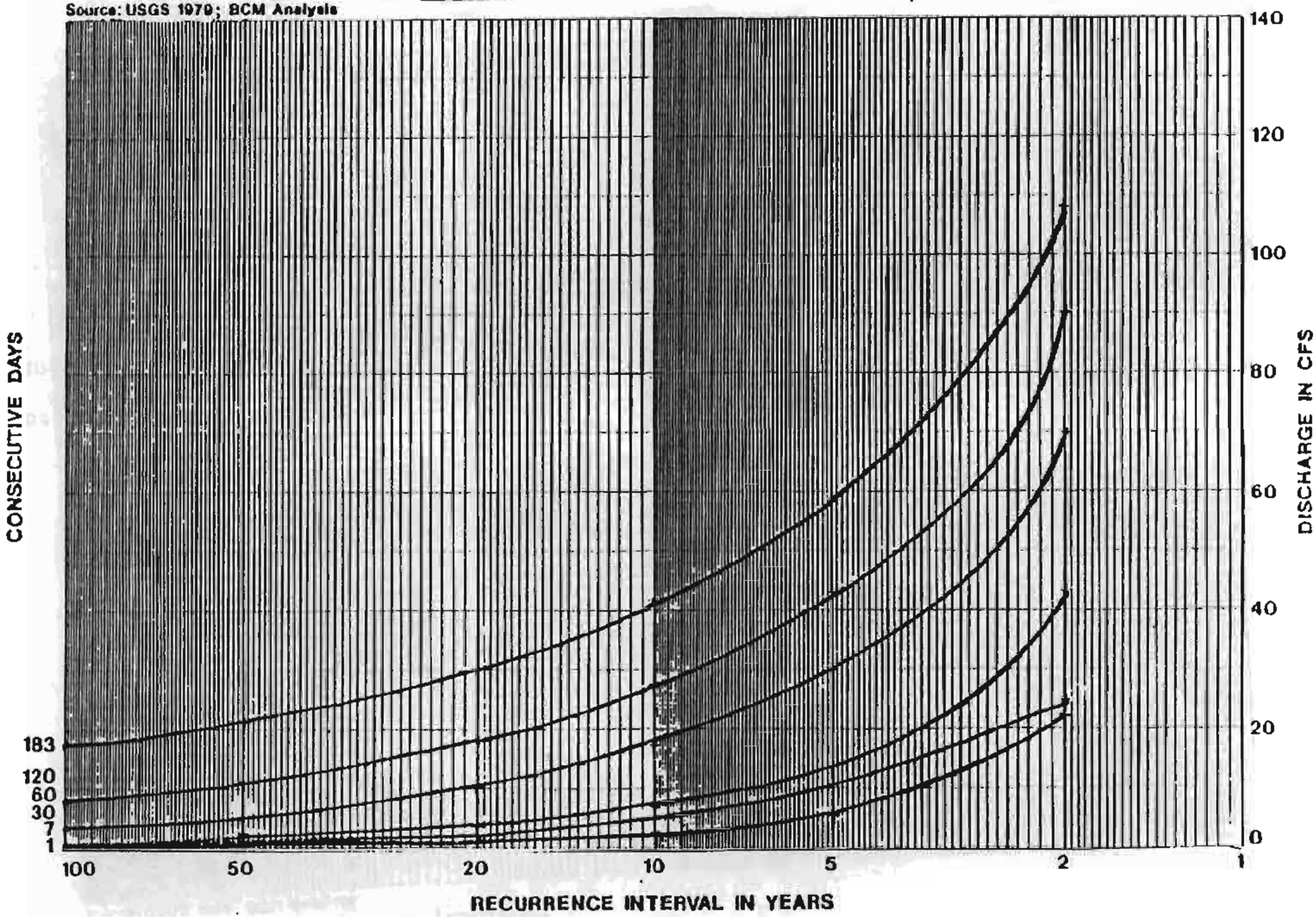
Source: USGS 1979; BCM Analysis



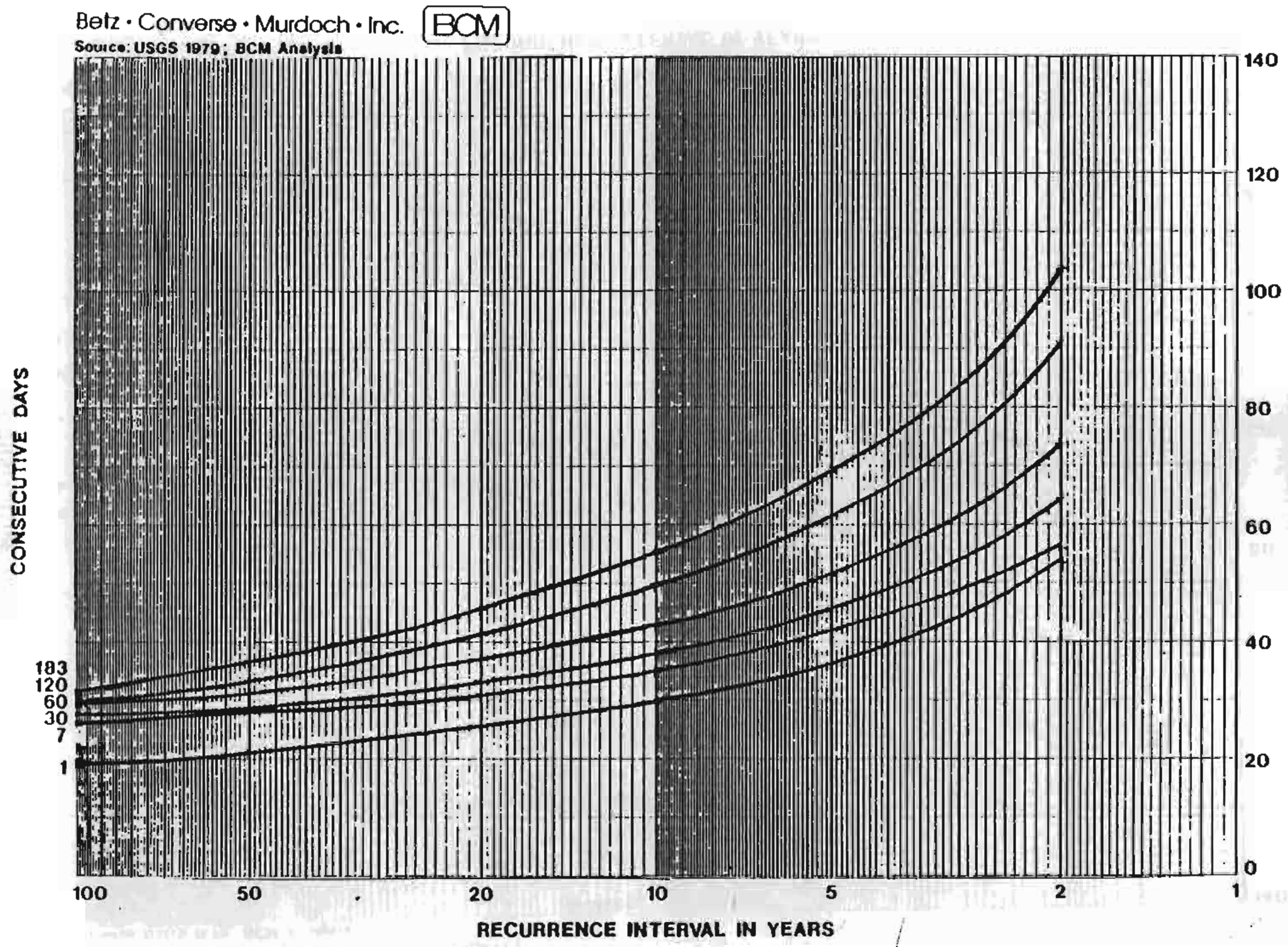
LOW FLOW FREQUENCY CURVES-GREAT EGG HARBOR RIVER AT FOLSOM (0141000)

Betz · Converse · Murdoch · Inc. BCM

Source: USGS 1979; BCM Analysis



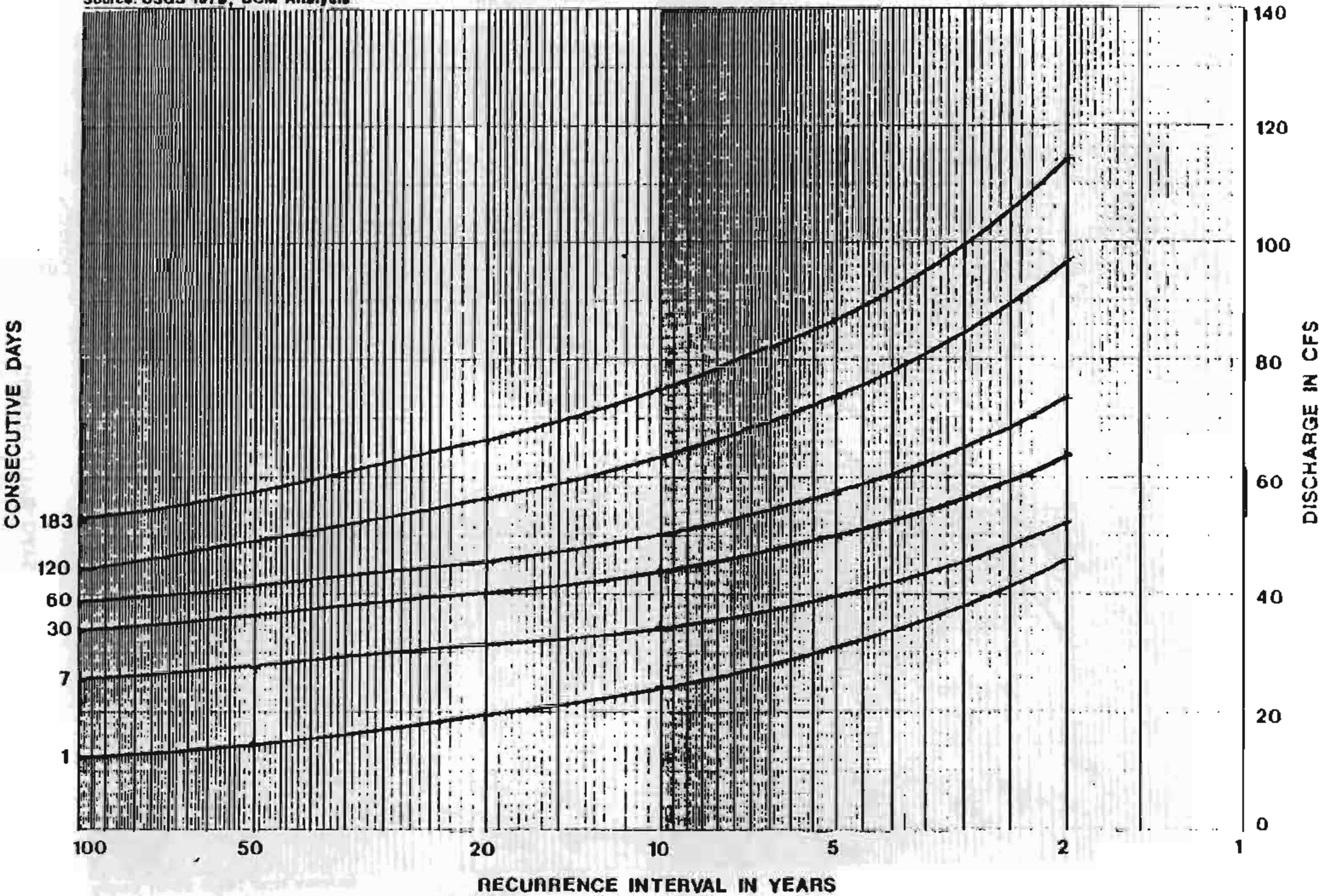
LOW FLOW FREQUENCY CURVES – ABSECON CREEK AT ABSECON (01410500)



LOW FLOW FREQUENCY CURVES–McDONALDS BRANCH AT LEBANON STATE FOREST (1466500)

Betz • Converse • Murdoch • Inc. BCM

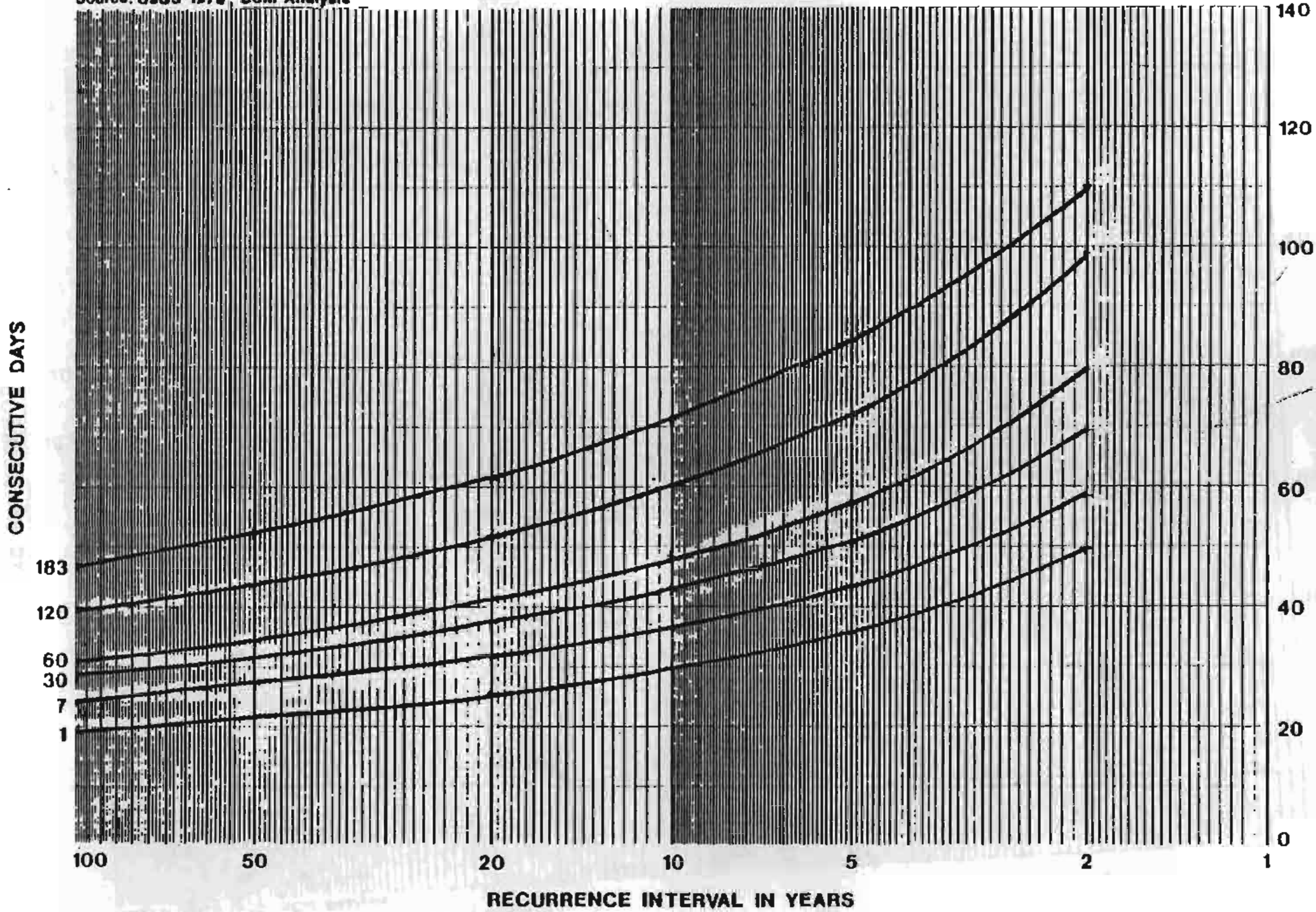
Source: USGS 1979; BCM Analysis



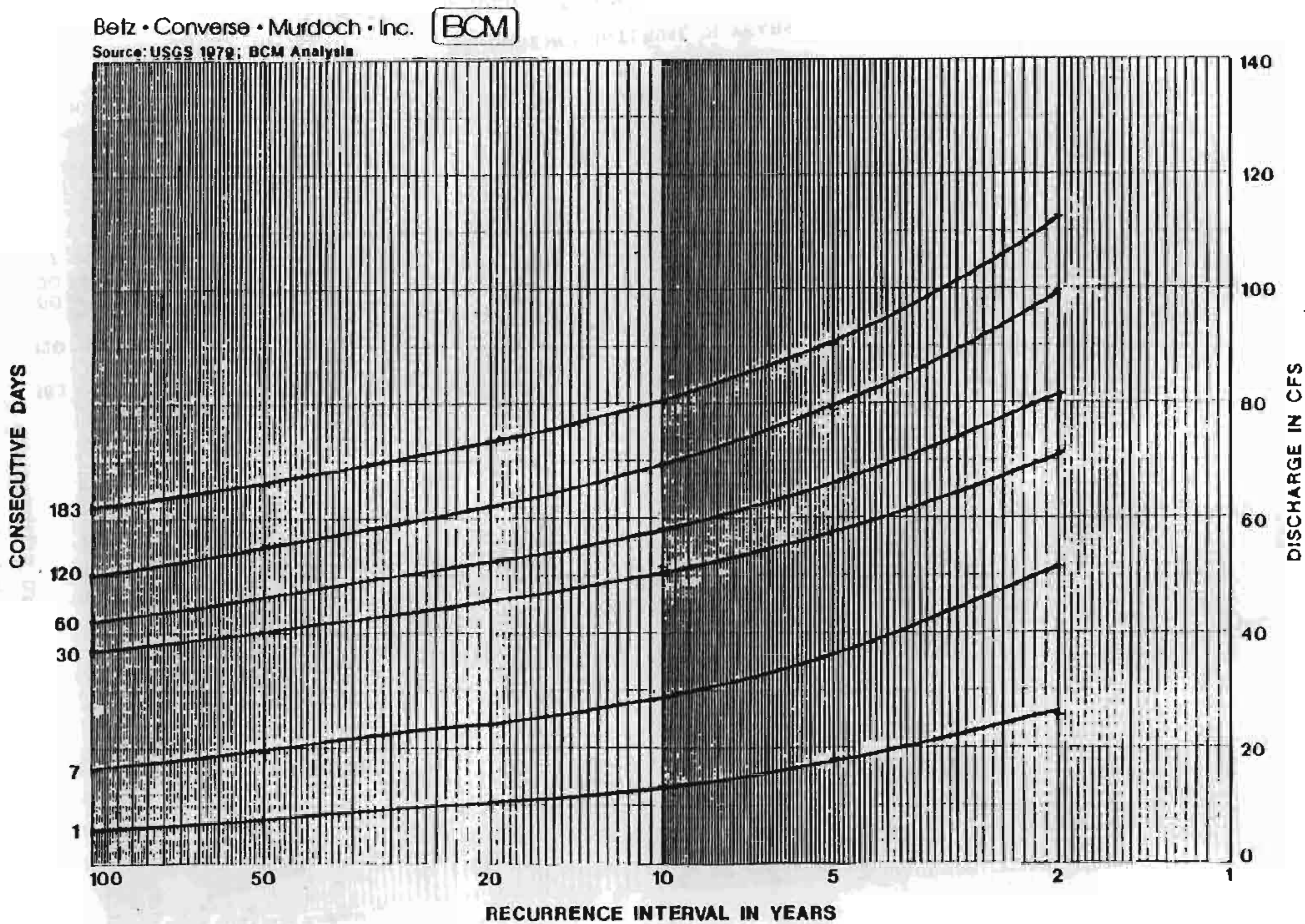
LOW FLOW FREQUENCY CURVES-N. BRANCH RANCOCAS CREEK AT PEMBERTON

Betz • Converse • Murdoch • Inc. BCM

Source: USGS 1979; BCM Analysis



LOW FLOW FREQUENCY CURVES—MAURICE RIVER (01411500)



LOW FLOW FREQUENCY CURVES-MANANTICO CREEK NEAR MILLVILLE (0141200)

APPENDIX 2

LIKELIHOOD OF EXCEEDANCE OF CALCULATED AND/OR ESTIMATED MEAN MONTHLY STREAMFLOWS

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 85%(1)	75%(1)	90%(1)	98%(1)
November						
	Toms River(2)	135.46	141	158	134	94
	North Branch Rancocas(3)	70.47	52	63	48	30
	South Branch Rancocas(4)	76.59	38	58	32	18
	Cedar Creek(5)	56.00	68	78	67	64
	Forked River(6)	19.70	25	28	24	23
	Oyster Creek(7)	11.26	30	33	29	26
	Mill Creek(8)	16.64	22	25	22	21
	Westecunk Creek(9)	19.00	23	27	22	17
	Bass River(10)	20.38	21	25	20	13
	Wading River(11)	146.39	147	172	136	86
	West Branch Wading(12)	84.10	93	109	86	55
	Oswego Creek(13)	64.00	52	62	47	31
	Batsto River(14)	70.50	74	87	69	43
	Atsion-Mechesactauxin Creeks(15)	64.40	58	60	40	14
	Nescochaque Creek(16)	41.09	42	49	39	25
	Hammonton Creek(17)	17.08	18	21	17	11
	Mullica River(18)	97.51	103	122	96	61
	Upper Great Egg Harbor River(19)	151.12	145	169	121	81
	Lower Great Egg Harbor River(20)	99.32	117	136	97	65
	Manumuskin Creek(21)	31.66	35	41	29	20
	Maurice River(22)	113.00	92	111	84	47
	Absecon River(23)	16.60	7	7	6	---
	Tuckahoe River(24)	69.68	41	43	41	41
	Dennis Creek(25)	71.60	52	54	52	52
	Patcong Creek(26)	25.92	19	20	19	19

TABLE 2-1

LIKELIHOOD OF EXCEEDANCE OF CALCULATED AND/OR ESTIMATED MEAN MONTHLY STREAMFLOWS

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 55%[1]	75%[1]	90%[1]	98%[1]
October						
	Toms River[2]	135.46	154	131	105	91
	North Branch Rancocas[3]	70.47	63	52	37	26
	South Branch Rancocas[4]	76.59	50	37	25	18
	Cedar Creek[5]	56.00	72	65	57	47
	Forked River[6]	19.70	28	27	22	18
	Oyster Creek[7]	11.26	39	33	30	29
	Mill Creek[8]	16.64	25	24	20	16
	Westecunk Creek[9]	19.00	25	22	19	15
	Bass River[10]	20.38	23	20	17	14
	Wading River[11]	146.39	157	136	117	96
	West Branch Wading[12]	84.10	100	86	74	61
	Oswego Creek[13]	64.00	59	45	36	29
	Batsto River[14]	70.50	72	62	54	44
	Atsion-Mechesactauxin Creeks[15]	64.40	65	37	29	21
	Nescochaque Creek[16]	41.09	45	39	33	27
	Hammonton Creek[17]	17.08	19	17	14	12
	Mullica River[18]	97.51	111	96	22	68
	Upper Great Egg Harbor River[19]	151.12	137	118	94	75
	Lower Great Egg Harbor River[20]	99.32	114	98	78	62
	Manumuskin Creek[21]	31.66	36	31	24	19
	Maurice River[22]	113.00	99	82	66	49
	Absecon River[23]	16.60	11	6	4	1
	Tuckahoe River[24]	69.68	50	43	34	27
	Dennis Creek[25]	71.60	65	56	44	35
	Patcong Creek[26]	25.92	24	21	17	13

Numbers in parenthesis refer to footnotes that can be found at the end of this table.

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 50%(1)	75%(1)	90%(1)	98%(1)
January						
	Toms River(2)	135.46	214	217	155	134
	North Branch Rancocas(3)	70.47	90	96	70	45
	South Branch Rancocas(4)	76.59	103	107	63	---
	Cedar Creek(5)	56.00	85	89	68	59
	Forked River(6)	19.70	30	31	24	21
	Oyster Creek(7)	11.26	35	36	30	24
	Mill Creek(8)	16.64	26	27	21	18
	Westecunk Creek(9)	19.00	30	33	23	17
	Bass River(10)	20.38	27	30	22	16
	Wading River(11)	146.39	186	206	147	107
	West Branch Wading(12)	84.10	118	131	93	68
	Oswego Creek(13)	64.00	73	80	60	34
	Batsto River(14)	70.50	97	107	77	56
	Atsion-Mechesactauxin Creeks(15)	64.40	110	111	81	22
	Nescochaque Creek(16)	41.09	53	59	42	31
	Hammonton Creek(17)	17.08	23	25	13	13
	Mullica River(18)	97.51	132	145	104	75
	Upper Great Egg Harbor River(19)	151.12	193	207	156	115
	Lower Great Egg Harbor River(20)	99.32	155	166	125	92
	Manumuskin Creek(21)	31.66	45	48	36	26
	Maurice River(22)	113.00	131	153	100	65
	Absecon River(23)	18.60	12	14	10	7
	Tuckahoe River(24)	69.68	77	84	57	43
	Dennis Creek(25)	71.60	79	86	58	44
	Patcong Creek(26)	25.92	29	32	22	16

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 83%[1]	75%[1]	90%[1]	98%[1]
December						
	Toms River[2]	135.46	161	175	147	105
	North Branch Rancocas[3]	70.47	67	70	54	36
	South Branch Rancocas[4]	78.59	104	115	64	---
	Cedar Creek[5]	56.00	75	79	72	53
	Forked River[6]	19.70	29	30	27	20
	Oyster Creek[7]	11.26	35	39	30	23
	Mill Creek[8]	16.64	25	27	24	18
	Westecunk Creek[9]	19.00	27	33	24	16
	Bass River[10]	20.38	25	30	22	15
	Wading River[11]	146.39	167	207	150	100
	West Branch Wading[12]	84.10	106	131	95	64
	Oswego Creek[13]	64.00	60	67	48	27
	Batsto River[14]	70.50	81	100	73	48
	Atsion-Mechesactauxin Creeks[15]	64.40	91	94	82	---
	Nescochaque Creek[16]	41.09	48	59	43	29
	Hammonton Creek[17]	17.08	21	25	18	12
	Mullica River[18]	97.51	118	146	106	71
	Upper Great Egg Harbor River[19]	151.12	172	191	153	94
	Lower Great Egg Harbor River[20]	99.32	134	149	119	73
	Manumuskin Creek[21]	31.66	38	43	34	21
	Maurice River[22]	113.00	112	121	103	57
	Absecon River[23]	16.60	7	11	5	---
	Tuckahoe River[24]	69.68	61	66	52	45
	Dennis Creek[25]	71.60	78	85	67	58
	Patcong Creek[26]	25.92	29	32	25	22

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 50%[1]	75%[1]	90%[1]	98%[1]
March						
	Toms River[2]	135.46	223	263	237	199
	North Branch Rancocas[3]	70.47	109	127	113	89
	South Branch Rancocas[4]	76.59	89	132	97	75
	Cedar Creek[5]	56.00	100	111	105	100
	Forked River[6]	19.70	38	42	40	38
	Oyster Creek[7]	11.26	30	42	35	23
	Mill Creek[8]	16.64	34	37	35	34
	Westecunk Creek[9]	19.00	36	44	38	30
	Bass River[10]	20.30	33	40	35	27
	Wading River[11]	146.39	224	275	238	186
	West Branch Wading[12]	84.10	142	175	151	118
	Oswego Creek[13]	64.00	77	95	84	60
	Batsto River[14]	70.50	112	138	119	93
	Atsion-Mechesactauxin Creeks[15]	64.40	113	125	109	73
	Nescochaque Creek[16]	41.09	64	79	68	53
	Hammonton Creek[17]	17.08	27	34	29	23
	Mullica River[18]	97.51	158	194	168	131
	Upper Great Egg Harbor River[19]	151.12	234	268	239	159
	Lower Great Egg Harbor River[20]	99.32	189	216	193	136
	Manumuskin Creek[21]	31.66	56	64	57	40
	Maurice River[22]	113.00	146	188	165	106
	Absecon River[23]	16.60	9	19	14	7
	Tuckahoe River[24]	69.68	70	97	75	53
	Dennis Creek[25]	71.60	71	98	78	63
	Patcong Creek[26]	25.92	26	36	28	24

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 83%(1)	75%(1)	90%(1)	98%(1)
February						
	Toms River(2)	135.46	216	241	189	154
	North Branch Rancocas(3)	70.47	104	110	96	60
	South Branch Rancocas(4)	76.59	109	126	94	90
	Cedar Creek(5)	56.00	95	105	86	73
	Forked River(6)	19.70	34	38	32	26
	Oyster Creek(7)	11.26	38	39	38	35
	Mill Creek(8)	16.54	30	33	29	23
	Westecunk Creek(9)	19.00	35	36	34	26
	Bass River(10)	20.38	32	33	31	24
	Wading River(11)	146.39	221	229	211	164
	West Branch Wading(12)	84.10	140	145	134	104
	Oswego Creek(13)	64.00	78	81	63	53
	Batsto River(14)	70.50	112	116	107	83
	Atsion-Mechesactauxin Creeks(15)	64.40	110	115	107	74
	Nescochague Creek(16)	41.09	63	66	61	47
	Hammonton Creek(17)	17.08	27	28	26	20
	Mullica River(18)	97.51	156	162	149	116
	Upper Great Egg Harbor River(19)	151.12	225	234	196	137
	Lower Great Egg Harbor River(20)	99.32	171	179	149	104
	Manumuskin Creek(21)	31.66	51	53	44	31
	Maurice River(22)	113.00	144	146	137	102
	Absecon River(23)	16.60	10	15	7	5
	Tuckahoe River(24)	69.68	66	81	61	59
	Dennis Creek(25)	71.60	67	92	62	60
	Patcong Creek(26)	25.92	25	31	23	22

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 83%[1]	75%[1]	90%[1]	98%[1]
May						
	Toms River[2]	135.46	196	210	175	130
	North Branch Rancocas[3]	70.47	80	81	77	62
	South Branch Rancocas[4]	76.59	58	64	52	36
	Cedar Creek[5]	56.00	88	93	79	72
	Forked River[6]	19.70	32	34	29	26
	Oyster Creek[7]	11.26	32	33	32	30
	Mill Creek[8]	16.64	29	30	26	23
	Westecunk Creek[9]	19.00	30	32	28	22
	Bass River[10]	20.38	27	30	26	20
	Wading River[11]	146.39	187	202	175	135
	West Branch Wading[12]	84.10	119	128	111	86
	Oswego Creek[13]	64.00	60	69	54	44
	Batsto River[14]	70.50	90	97	84	65
	Atsion-Mechesactauxin Creeks[15]	64.40	72	78	64	48
	Nescochaque Creek[16]	41.09	54	58	50	39
	Hammonton Creek[17]	17.08	23	25	21	17
	Mullica River[18]	97.51	132	143	123	96
	Upper Great Egg Harbor River[19]	151.12	158	188	142	126
	Lower Great Egg Harbor River[20]	99.32	121	144	109	96
	Manumuskin Creek[21]	31.66	34	41	31	27
	Maurice River[22]	113.00	115	138	95	80
	Absecon River[23]	16.60	12	13	9	---
	Tuckahoe River[24]	69.68	61	72	43	29
	Dennis Creek[25]	71.60	56	78	46	31
	Patcong Creek[26]	25.92	25	29	17	12

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 85%(1)	75%(1)	90%(1)	98%(1)
April						
	Toms River(2)	135.46	212	229	204	164
	North Branch Rancocas(3)	70.47	94	103	88	80
	South Branch Rancocas(4)	76.59	80	93	74	63
	Cedar Creek(5)	56.00	101	105	98	93
	Forked River(6)	19.70	37	38	36	34
	Oyster Creek(7)	11.26	36	39	33	26
	Mill Creek(8)	16.64	32	34	31	30
	Westecunk Creek(9)	19.00	31	36	30	24
	Bass River(10)	20.38	28	33	27	22
	Wading River(11)	146.39	191	225	187	152
	West Branch Wading(12)	84.10	121	143	118	97
	Oswego Creek(13)	64.00	73	81	69	42
	Batsto River(14)	70.50	94	111	92	75
	Atsion-Mechesactauxin Creeks(15)	64.40	89	93	78	50
	Nescochague Creek(16)	41.09	55	65	54	44
	Hammonton Creek(17)	17.08	24	28	23	19
	Mullica River(18)	97.51	135	159	133	107
	Upper Great Egg Harbor River(19)	151.12	204	225	196	150
	Lower Great Egg Harbor River(20)	99.32	161	178	155	118
	Manumuskin Creek(21)	31.66	49	54	47	36
	Maurice River(22)	113.00	152	164	142	91
	Absecon River(23)	16.60	13	17	12	5
	Tuckahoe River(24)	69.68	68	81	61	59
	Dennis Creek(25)	71.60	73	88	66	64
	Patcong Creek(26)	25.92	27	33	25	24

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 70%[1]	75%[1]	90%[1]	98%[1]
July						
	Toms River[2]	135.46	120	117	102	93
	North Branch Rancocas[3]	70.47	49	47	39	29
	South Branch Rancocas[4]	76.59	43	40	20	13
	Cedar Creek[5]	56.00	69	68	58	40
	Forked River[6]	19.70	27	26	23	16
	Oyster Creek[7]	11.26	35	32	26	23
	Mill Creek[8]	16.64	26	23	20	14
	Westecunk Creek[9]	19.00	23	20	17	14
	Bass River[10]	20.38	21	19	16	12
	Wading River[11]	146.39	141	127	108	85
	West Branch Wading[12]	84.10	90	81	69	54
	Oswego Creek[13]	64.00	45	41	35	24
	Batsto River[14]	70.50	68	61	52	41
	Atsion-Mechesactauxin Creeks[15]	64.40	47	44	28	19
	Nescochaque Creek[16]	41.09	41	36	31	24
	Hammonton Creek[17]	17.08	17	16	13	10
	Mullica River[18]	97.51	100	89	76	60
	Upper Great Egg Harbor River[19]	151.12	118	110	86	62
	Lower Great Egg Harbor River[20]	99.32	99	93	72	52
	Manumuskin Creek[21]	31.66	33	31	24	17
	Maurice River[22]	113.00	91	30	54	36
	Absecon River[23]	16.60	6	4	1	0
	Tuckahoe River[24]	69.68	34	32	32	32
	Dennis Creek[25]	71.60	41	39	39	39
	Patcong Creek[26]	25.92	15	14	14	14

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 70%(1)	75%(1)	90%(1)	98%(1)
June						
	Toms River(2)	135.46	161	158	131	106
	North Branch Rancocas(3)	70.47	63	57	46	36
	South Branch Rancocas(4)	76.59	43	42	23	17
	Cedar Creek(5)	56.00	84	80	71	56
	Forked River(6)	19.70	36	31	27	22
	Oyster Creek(7)	11.26	35	33	27	24
	Mill Creek(8)	16.64	32	27	24	19
	Westecunk Creek(9)	19.00	24	29	20	16
	Bass River(10)	20.38	22	26	19	15
	Wading River(11)	146.39	153	143	127	68
	West Branch Wading(12)	84.10	97	91	80	65
	Oswego Creek(13)	64.00	52	51	42	34
	Batsto River(14)	70.50	76	71	63	51
	Atsion-Mechesactauxin Creeks(15)	64.40	51	49	39	28
	Nescochaque Creek(16)	41.09	108	52	36	29
	Hammonton Creek(17)	17.08	19	22	16	13
	Mullica River(18)	97.51	108	127	89	72
	Upper Great Egg Harbor River(19)	151.12	134	132	110	94
	Lower Great Egg Harbor River(20)	99.32	111	110	92	78
	Manumuskin Creek(21)	31.68	34	34	28	24
	Maurice River(22)	113.00	116	108	74	58
	Absecon River(23)	16.60	9	8	5	---
	Tuckahoe River(24)	69.68	52	50	32	23
	Dennis Creek(25)	71.60	52	50	32	23
	Patcong Creek(26)	25.92	19	19	12	9

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 70%[1]	75%[1]	90%[1]	98%[1]
September						
	Toms River[2]	135.46	114	108	85	76
	North Branch Rancocas[3]	70.47	47	43	34	27
	South Branch Rancocas[4]	76.59	26	24	17	15
	Cedar Creek[5]	56.00	66	63	56	38
	Forked River[6]	19.70	24	23	21	14
	Oyster Creek[7]	11.26	33	33	27	18
	Mill Creek[8]	16.64	22	21	18	12
	Westecunk Creek[9]	19.00	23	22	18	17
	Bass River[10]	20.38	21	20	17	16
	Wading River[11]	146.39	144	139	113	108
	West Branch Wading[12]	84.10	91	88	72	69
	Oswego Creek[13]	64.00	40.3	38	29	24
	Batsto River[14]	70.50	60	58	47	45
	Atsion-Mechesactauxin Creeks[15]	64.40	36	33	23	23
	Nescochaque Creek[16]	41.09	41	40	32	31
	Hammonton Creek[17]	17.08	18	17	14	13
	Mullica River[18]	97.51	102	97	80	76
	Upper Great Egg Harbor River[19]	151.12	107	97	75	70
	Lower Great Egg Harbor River[20]	99.32	102	92	72	67
	Manumuskin Creek[21]	31.66	36	33	25	24
	Maurice River[22]	113.00	73	68	49	41
	Absecon River[23]	16.60	7	6	3	1
	Tuckahoe River[24]	69.68	36	34	32	32
	Dennis Creek[25]	71.60	46	44	41	41
	Patcong Creek[26]	25.92	17	16	15	15

TABLE 2-1 (Continued)

Month	Basin	Drainage Area (Square Miles)	Calculated and/or Estimated Mean Monthly Streamflows (cfs) 70%[1]	75%[1]	90%[1]	98%[1]
August						
	Toms River[2]	135.46	113	116	98	63
	North Branch Rancocas[3]	70.47	43	45	34	27
	South Branch Rancocas[4]	76.59	21	25	17	17
	Cedar Creek[5]	56.00	64	70	54	36
	Forked River[6]	19.70	28	31	24	16
	Oyster Creek[7]	11.26	36	36	30	26
	Mill Creek[8]	16.64	25	27	21	14
	Westecunk Creek[9]	19.00	22	23	18	16
	Bass River[10]	20.38	20	21	16	15
	Wading River[11]	146.39	136	143	112	100
	West Branch Wading[12]	84.10	86	91	71	64
	Oswego Creek[13]	64.00	39	44	36	24
	Batsto River[14]	70.50	57	60	47	42
	Atsion-Mechesactauxin Creeks[15]	64.40	32	37	23	19
	Mescochaque Creek[16]	41.09	39	41	32	29
	Hammonton Creek[17]	17.08	17	18	14	12
	Mullica River[18]	97.51	96	101	79	71
	Upper Great Egg Harbor River[19]	151.12	97	102	75	51
	Lower Great Egg Harbor River[20]	99.32	85	89	66	45
	Manumuskin Creek[21]	31.66	28	30	22	15
	Maurice River[22]	113.00	69	73	52	35
	Absecon River[23]	16.60	5	5	2	1
	Tuckahoe River[24]	69.68	41	41	36	32
	Dennis Creek[25]	71.60	52	52	46	41
	Patcong Creek[26]	25.92	20	20	17	15

TABLE 2-1 (Continued)

Notes:

1. Percentage of years which flow is likely to exceed the given flow value. The likelihood of exceedance in column 3 is based on work conducted on the Batsto River and the Mullica River estuary (Durand and Nadeau, 1972, p. 68) and USGS flow data for the Batsto River. The 75%, 90%, and 98% likelihoods of exceedance were selected in order to provide a range of flow values.

2. Flows at USGS gage (drainage area = 124 sq. mi.) arithmetically adjusted on the basis of drainage area to include area downstream from gage.

3. Flows at USGS gage (drainage area = 111 sq. mi.) arithmetically adjusted on the basis of drainage area to include only portion of drainage basin within Pinelands National Reserve boundary.

4. Flows at USGS gage (drainage area = 64.5 sq. mi.) arithmetically adjusted on the basis of drainage area to include only portion of drainage basin within Pinelands National Reserve boundary.

5. USGS streamflow gage at basin mouth. No adjustment required.

6. Ungaged watershed. Flows extrapolated from Cedar Creek data base.

7. Flows adjusted for drainage area downstream from USGS streamflow gaging station.

8. Ungaged watershed. Flows extrapolated from Cedar Creek data base.

9. USGS streamflow gage at basin mouth. No adjustment required.

10. Ungaged watershed. Flows extrapolated from Batsto River data base.

11. Ungaged at mouth. Flows extrapolated from Batsto River data base.

12. Gaged record of insufficient length. Flows extrapolated from Batsto River data base.

13. USGS streamflow gage at basin mouth. No adjustment required.

14. USGS streamflow gage at basin mouth. No adjustment required.

15. Mullica River USGS stream gaging station. No adjustment required.

16. Ungaged watershed. Flows extrapolated from Batsto River data base.

17. Ungaged watershed. Flows extrapolated from Batsto River data base.

18. Ungaged watershed. Flows extrapolated from Batsto River data base. Flows composed of inflows from numerous small tributaries.

19. Flows at USGS gage (drainage area = 56.3 sq. mi.) arithmetically adjusted on the basis of drainage area to include area downstream from gage.

20. Ungaged watershed. Flows extrapolated from Great Egg Harbor River at Folsom data base.

21. Ungaged watershed. Flows extrapolated from Maurice River data base.

22. Flows computed at USGS streamflow gaging station. No adjustment has been made to include downstream basin area.

23. USGS streamflow station near mouth. No adjustment made.

24. Flows at USGS streamflow gaging station (drainage area = 30.8 sq. mi.) arithmetically adjusted to include full drainage area. Flow rates include contribution from numerous small tributaries draining directly to the estuary.

25. Ungaged watershed. Flows extrapolated from the Tuckahoe River data base. Estimated flows include flow from numerous tributaries draining directly to the estuary.

26. Ungaged watershed. Flows extrapolated from the Tuckahoe River data base. Estimated flows include flow from numerous tributaries draining directly to the estuary.

TECHNICAL MEMORANDUM SW III-2

POTENTIAL IMPACT OF DEVELOPMENT ON FLOW REGIMES

PINELANDS COMMISSION

FEBRUARY 1980

BETZ•CONVERSE•MURDOCH•INC.
ONE PLYMOUTH MEETING MALL
PLYMOUTH MEETING, PENNSYLVANIA 19462

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POTENTIAL IMPACT OF DEVELOPMENT ON FLOW REGIMES

INTRODUCTION

The flow characteristics, or flow regimes, of the streams and drainage basins of the Pinelands National Reserve (Figure 1) are a function of the physical characteristics of the area: low relief, sandy soils, water table aquifer; the meteorological characteristics: fairly uniform monthly rainfall distribution, variability of annual precipiation; and the land cover/land uses of the area: highly forested, little urban development. Information contained in Technical Memorandum SW III-1 indicated the variability of some of those factors; for example, basin soil characteristics significantly affect streamflow distribution. The objective of this technical memorandum is to describe the potential impacts that a change in one of these factors--land use--could have on Pinelands streams. Knowledge of the potential impacts of land use change on streamflow is essential for the sound management of development and the water resources of the region. Focus is placed on the potential alterations to the existing rainfall-direct runoff relationships of Pinelands watersheds, and the consequent impacts on groundwater recharge. Measures which may be used to mitigate the impacts of urban development on Pinelands flow regimes are described in the latter part of this technical memorandum.

Documentation of the impacts of urbanization on flood flow rates is extensive (Leopold, 1968). Other impacts include lower base streamflows, decreased elevations of the water table, surface and groundwater contamination and stream channel enlargement. Because of the general lack of major urban development in the Pinelands, and lack of streamflow recording stations in the few areas where development is significant, experience with the impacts of urban development on streamflow must be obtained from other areas. Information obtained over a 30-year period from portions of Long Island, New York, an area that shares many hydrologic similarities with the Pinelands, is presented in the following sections. In addition, four small urbanized Pinelands watersheds were analyzed to determine the potential impacts of development on Pinelands streams.

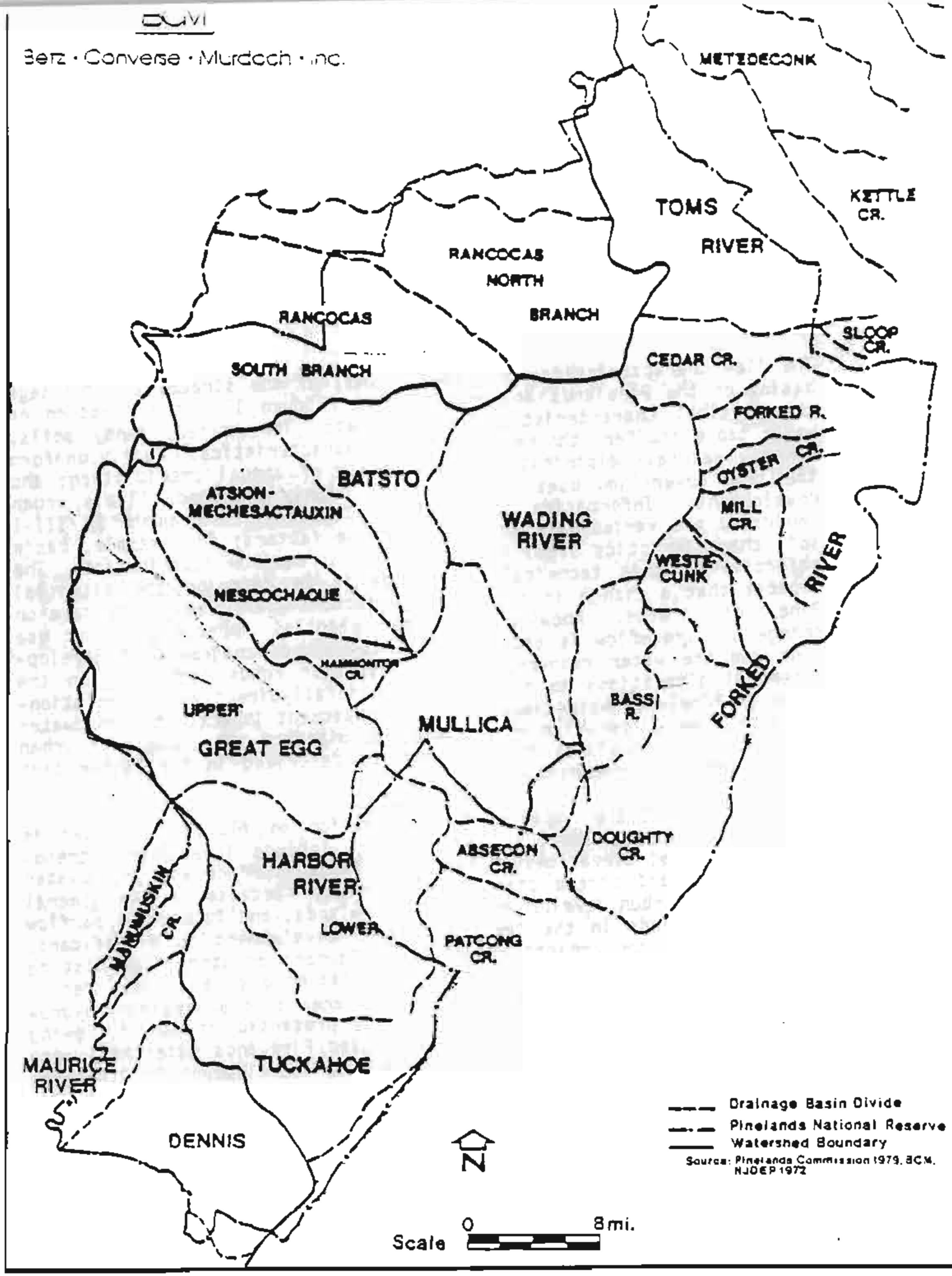

Figure 1. PINELANDS DRAINAGE BASINS

THE LONG ISLAND EXPERIENCE

Nassau County in western Long Island, New York was selected for the description of impacts of development for two reasons:

1. Only two Pinelands area watersheds containing continuous streamflow measuring devices are significantly affected by urban development. Water withdrawals for the Atlantic City water supply are taken from Absecon Creek. The Great Egg Harbor River Tributary at Sicklersville, Camden County, located just outside the Pinelands National Reserve boundary, contains a large, recently constructed residential development. Absecon Creek represents the impacts of large-scale water supply development on a streamflow. Although the impact is significant, its usefulness as an example is limited because it represents only one type of urban use. An analysis of the Sicklersville gage indicates that it is likely that the urbanization has had a major impact on streamflow. However, the short period of record (6 years) and an especially insufficient predevelopment record of streamflow preclude its use for the current discussion.

2. Long Island, located approximately 60 miles from the northeast corner of the Pinelands National Reserve, has hydrologic characteristics similar to the Pinelands. Soils are primarily composed of sands and gravels and are very well, to excessively drained. Rainfall-runoff relationships, including amounts of annual precipitation, evapotranspiration and total runoff, as well as percentages of direct and base flow runoff, are similar to that of the Pinelands. In addition, an unconfined water table aquifer is found in both areas.

Long Island, which extends eastward from the mainland of New York State, has a total area of 1,400 square miles. Nassau and Suffolk counties, which occupy approximately 85% of the area, had a combined population of over 3 million people in 1975. Most of the information used for this discussion is based on investigations conducted by the U.S. Geological Survey in cooperation with New York state and county agencies. Reports by Sawyer (1963), Pluhowski and Kantrowitz (1964) and Seaburn (1969) are the primary sources for the information presented in the following discussion.

A detailed hydrologic investigation of the impacts of urban development on direct runoff to East Meadow Brook* during the period 1937-66 was made by Seaburn (1969). The specific objectives of his study were:

1. To relate indices of urban development to increases in the volume of annual direct runoff to the stream

2. To compare hydrograph features at different periods during the transition of the drainage basin from rural to urban conditions

3. To compare the rainfall-runoff relationship for periods before and after development

Periods of housing and street construction in the watershed correspond to three distinct periods of increased direct runoff. During each period, the average annual direct runoff increased because of an increase in the percentage of impervious surface and the area served by storm sewers that discharge into East Meadow Brook. The amount of land served by sewers in the 31-square-mile drainage basin increased from about 570 acres in 1943 to about 3,600 acres in 1962, or about 530 percent. During this period, the average annual direct runoff increased from about 920 acre-feet per year to about 3,400 acre-feet per year, or to about 270% of the pre-1943 direct flow.

Peak rates of direct storm runoff also increased during the period of study. The average peak discharge of 1-hour duration unit hydrograph increased from 313 cubic feet per second for storms during 1937-43, to 776 cubic feet per second for storms during 1960-62, or about 2.5 times.

An analysis of the rainfall-runoff relationships for both pre-urban and urban land use conditions indicated that the direct runoff for both periods increased with the magnitude of the storm. However, the direct runoff after urbanization was 1.1 to 4.6 times greater than the corresponding runoff during the pre-urban condition, depending upon the magnitude of the individual storm.

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* The East Meadow Brook's drainage basin comprises about 31 square miles. However, the upper 21 square miles, which consists largely of forested estates, produces virtually no direct runoff (Seaburn, 1969). Therefore, the area of possible direct runoff conditions is limited to the 10 square miles in the downstream portion of the basin.

The volume of direct runoff from the portion of the drainage basin with storm sewers that discharge into East Meadow Brook was estimated to have been 3,000 acre-feet per year in 1960-62, or about 20% of the precipitation over the area. Precipitation during the 1960-62 period averaged 46.7 inches per year, only 0.7 inches greater than the average annual rate of 46 inches per year (Pluhowski and Kantrowitz, 1964). Therefore, it can be assumed that during an average year, approximately 9.4 inches of direct runoff would be produced from the sewered area. Estimates by Sawyer (1963) for an un-urbanized watershed adjacent to East Meadow Brook and by Pluhowski and Kantrowitz (1964) in less urbanized Suffolk County, indicate that average annual direct runoff for un-urbanized areas is approximately one inch per year. Therefore, it can be assumed that in areas which are urbanized, storm-sewered and do not have stormwater retention basins, annual direct runoff can be as much as 9.4 times greater than under pre-urban conditions.

Seaburn stated (1969) that the increase in direct runoff for the East Meadow Brook drainage basin probably represented a loss of groundwater recharge. Other variables, including possible changes in evaportranspiration and the impacts from cesspools and septic tanks and recharge basins, precluded Seaburn from estimating the impact of development on groundwater recharge. However, because approximately 50% of Long Island precipitation recharges the groundwater reservoir, 4.2 inches (50%) of the additional direct runoff represents loss of recharge. Therefore, assuming that domestic water demand and wastewater treatment are not also altering the basin hydrology, the increased direct runoff would decrease groundwater recharge by 18%, from 24 inches to 19.8 inches. Lower recharge rates would result in a lower water table and lower base streamflow.

Seaburn concluded that without stormwater retention, construction of additional storm sewers and/or increased impervious surfaces in the existing sewered area would further increase direct runoff and, as a result, would reduce the water available to recharge the groundwater reservoir.

POTENTIAL IMPACTS OF DEVELOPMENT ON PINELANDS SURFACE WATER FLOW CHARACTERISTICS

Information on the impacts of urban development on Pinelands streams is largely unavailable, primarily because most of the region does not have significant concentrations of residential, commercial and industrial development. Nevertheless, an indication of the potential impact of urbanization on Pinelands streams is available from the streamflow data for the Great Egg Harbor River Tributary at Sicklersville. Approximately 20% of the watershed is in agricultural land use. A recently constructed residential subdivision occupies an additional 20% of the basin. A comparison of the relationships between rainfall and runoff at the Sicklersville stream gage with the rainfall-runoff relationship measured from the stream gage data for the Tuckahoe River at Head of River indicates a significant difference in the response of the watersheds to rainfall events of similar magnitudes. The Tuckahoe River basin was selected for comparison with the Great Egg Harbor Tributary because it is largely undeveloped and has a similar distribution of hydrologic soil groups* (Table 1). To develop the comparison, the volume of direct runoff for several storm events was estimated using the hydrograph separation technique described in Technical Memorandum SW III-1. Storm rainfall amounts were developed by synthesizing basin rainfall from daily rainfall information from the nearby precipitation gaging stations. The differences in drainage basin area was accounted for by dividing the volume of runoff by the drainage area of each basin. The relationship between rainfall and direct runoff for the two drainage basins is presented in Figure 2. For example, the analysis indicates that approximately 0.33 inches of direct runoff may be expected to result from a 2-inch rainstorm (13.6% of 2-inch rainfall) upstream from the Sicklersville gage. Runoff in the Tuckahoe River watershed would be expected to be about 0.10 inches (5% of 2-inch rainfall). Direct runoff in the urbanized basin appears to be significantly greater than for a relatively similar, but undeveloped watershed.

To supplement the limited amount of empirical information on the impact of urbanization on Pinelands surface water hydrology, a series of hypothetical development scenarios were designed. Four small Pinelands drainage basins--Biddle Branch, Cooks Branch, Pole Bridge Branch and Clarks Branch--were selected for the analysis of the impact of the development scenarios on streamflow. These four tributaries, locations of which are shown in Figure 3, were selected because they are not urbanized, they are in different sections of the Pinelands, and because they display differing topographic and soil characteristics. No continuous streamflow records are available for any of the streams.

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* Technical Memorandum SW III-1 contains an analysis which indicates that in undeveloped watersheds direct runoff is related to a basin's soil characteristics. An explanation of the various soil groups is presented in later paragraphs of this technical memorandum.

TABLE 1

DRAINAGE BASIN SOIL GROUPS

Drainage Basin	Soils Groups*								Total square miles
	A		B		C		D		
	sq. mi.	%	sq. mi.	%	sq.mi.	%	sq.mi.	%	
Great Egg Harbor River Tributary at Sicklersville	0	0	0.90	57.8	0.43	27.7	0.23	14.5	1.56
Tuckahoe River at Head of River	0.72	2.3	18.09	58.8	7.51	24.4	4.44	14.5	30.76

* Descriptions of the SCS hydrologic soil groups and listing of the hydrologic group of each Pinelands soil series are presented in Appendix 1.

Betz • Converse • Murdoch • Inc. BCM
Source: BCM

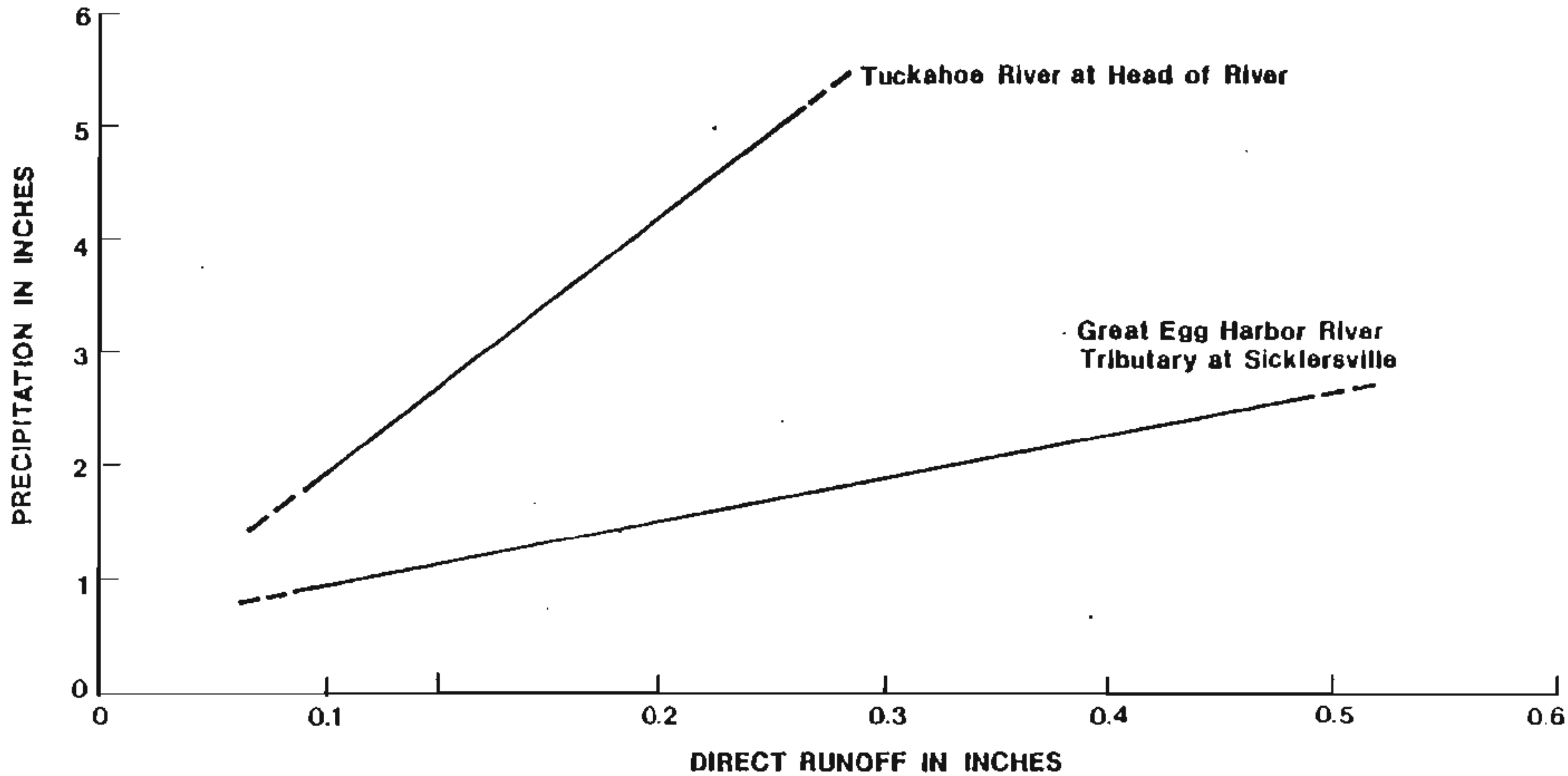

Figure 2. RAINFALL-RUNOFF RELATIONSHIPS

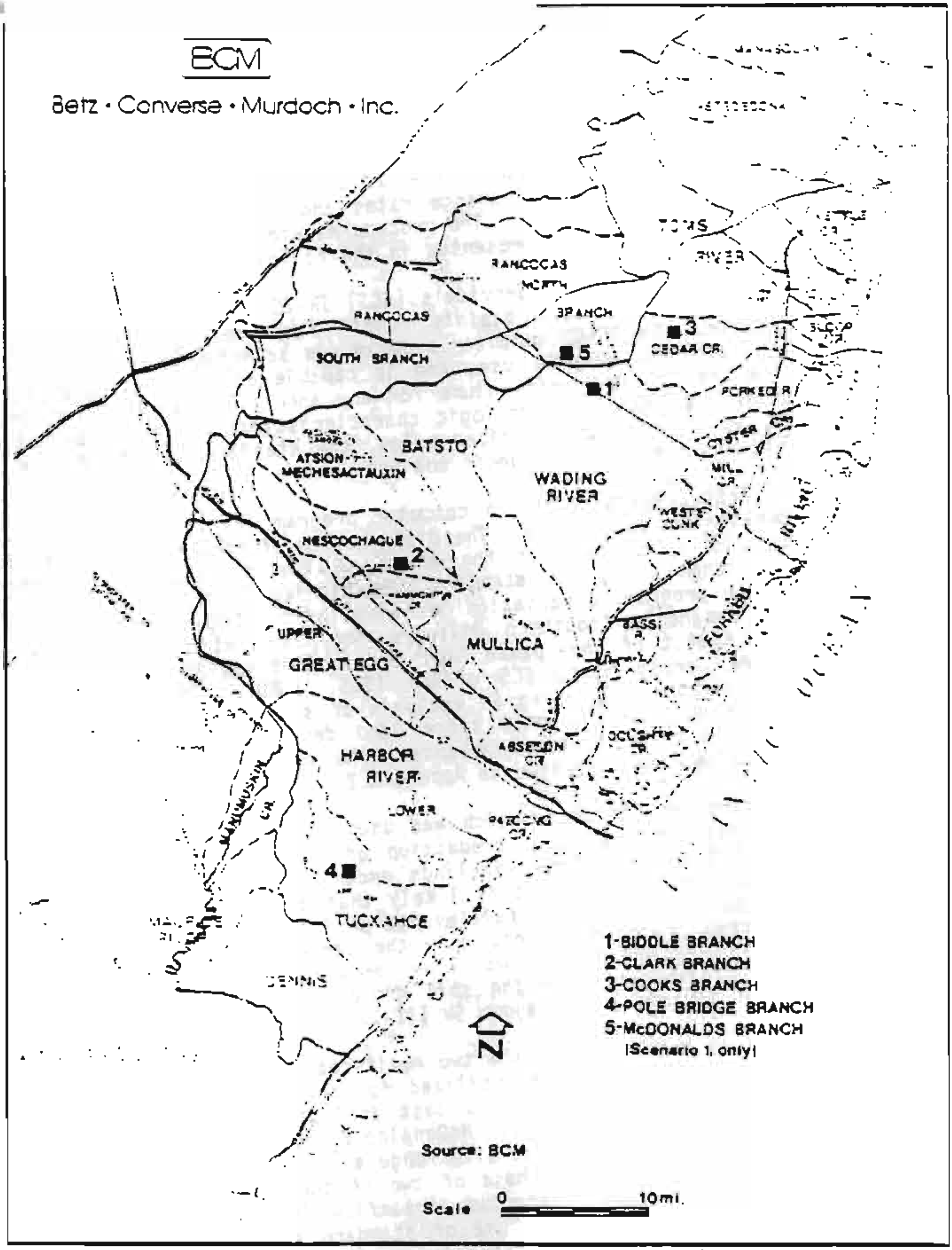

Figure 3. LOCATIONS OF SCENARIO DRAINAGE BASINS

The hypothetical development scenarios which were evaluated to determine drainage basin peak discharge rates and rainfall-runoff relationships are outlined in Table 2. The procedures used for and the results of the scenario analysis are presented in the following paragraphs.

The Soil Conservation Service's (SCS) TR-20 computer model was used in the analysis of each basin's runoff response to rainfall for each scenario. The TR-20 computer program was selected because it is generally accepted, easy to use, and is capable of calculating peak runoff rates and direct runoff volume for any amount of rainfall for drainage basins with varying hydrologic characteristics. With the exception of the two adjustments described below, the standard runoff routine (SCS, 1965) was used for the runoff analysis.

The first adjustment to the computer program was the use of a modified dimensionless hydrograph. The distribution of flow in the runoff hydrograph is a function of the shape of the dimensionless hydrograph. Rather than using the standard dimensionless hydrograph in the TR-20 computer program, a variation developed by the SCS for use on the Delmarva peninsula (southern Delaware and the portions of Maryland and Virginia east of Chesapeake Bay) was substituted at the suggestion of the New Jersey State SCS office (SCS, 1980). This hydrograph was derived by the SCS during an analysis of storm runoff on gaged streams draining basins with mild slopes and densely vegetated flood plains similar to those in the Pinelands. The modified dimensionless hydrograph values are presented in Appendix 2.

The second modification, which was used in Scenarios 1 and 2, relates to "effective" areas for production of direct stormwater runoff. In forested portions of the Pinelands underlain by soils in the A and B hydrologic soil groups, it is likely that direct runoff does not occur except during extreme rainfall events or frozen ground conditions. For undeveloped drainage basins, only the percentage of the drainage area underlain by C and D soils was used for the first two scenarios. Additional information regarding soil groups-runoff relationships is presented in Technical Memorandum SW III-1.

In order to check whether the two modifications described above and the other assumptions and data utilized for the TR-20 model would produce reasonably accurate results, a test analysis of the McDonalds Branch drainage basin was conducted. McDonalds Branch was selected because its drainage area is in the same size range as the scenario basins, its soil characteristics resemble those of two of the selected basins, and the period of continuously recorded streamflow information is sufficiently long enough to warrant the use of standard statistical procedures for estimating peak flood flow rates for various recurrence intervals.

TABLE 2

LAND DEVELOPMENT SCENARIOS

Scenario Number	Land Use Description*	Drainage Basin: Biddle Branch	Cooks Branch	Pole Bridge Branch	Clarks Branch
1	Existing land use	X	X	X	X
2	Pre-agricultural land use				X
3	Residential development (1 home/acre); complete storm sewering	X	X	X	X
4	Cluster residential (3 homes/acre, 1-acre gross density); no storm sewers	X	X	X	X
5	Multiple land uses: Residential single-family (4 homes/acre) 17% Residential multi-family 17% Commercial 17% Light Industrial 17% Open Space 32%	X	X	X	

* Development in scenarios 3, 4 and 5 was excluded from areas of permanently high water table (D soils). Percentages of the hydrologic soil groups in each basin are found in Table 3.

TABLE 3

HYDROLOGIC SOIL GROUPS OF MCDONALDS BRANCH AND SCENARIO DRAINAGE BASINS

Drainage Basin	Soils Groups**								Total
	A		B		C		D		
	sq. mi.	%	sq. mi.	%	sq. mi.	%	sq. mi.	%	square miles
McDonalds Branch									
Lebanon State Forest streamflow station	2.07	77.5	.31	11.7	.22	8.3	.07	2.5	2.67*
Biddle Branch upstream from junction with Pope Branch	2.13	77	0.27	9.6	0.25	9	.13	4.6	2.78
Clarks Branch upstream from Pestleton Road	.07	3.6	1.13	58.0	.66	33.8	.09	4.6	1.95
Cooks Branch upstream from Bamber Lake	1.82	50.8	1.15	32.1	.20	5.6	.41	11.5	3.58
Pole Bridge Branch upstream from First Avenue	.04	1.1	2.38	67.9	.51	14.5	.58	16.5	3.51

* Drainage area determined with assistance of aerial photographs and soils maps. Adjustments to drainage divide were made on USGS quadrangle maps and area was measured. The measured area, 2.67 square miles, is 0.3 miles larger than the area published in the USGS reports.

** Source: New Jersey Pinelands Commission - maps
Soil area tabulation - BCM

TABLE 4

TR-20 INPUT DATA, MCDONALDS BRANCH

Category	Input Value	Comments
Drainage Area	0.29 square miles	Area of C and D soils within basin assumed to be effective area for generation of direct runoff
Runoff Curve Number (RCN)	72	Weighted RCN for forest land with good cover and 77% C soils (RCN 70) and 23% D soils (RCN 77)*
Time of Concentration (TC)	10.4 hours	Based on travel length of 15,200 feet from upstream limit of effective area to basin mouth. Average velocity of 0.4 ft/second based on use of Manning's Formula with the estimated average channel dimensions 4 ft x 1.5 ft, slope = 0.002.
24-Hour Rainfall**	2-year - 3.5 in. 10 year - 5.3 in. 100 year - 7.5 in.	SCS Type II Rainfall Distribution used
Antecedent Moisture Condition (AMC)	AMC-2	Average conditions as specified in NEH-4***

* Source: SCS, 1976

** Source: United States Department of Commerce, 1961

*** Source: SCS, 1972

Topographic and soils maps of the McDonalds Run drainage basin are presented in Appendices 3 and 4. Computation of the area of each hydrologic soils group is presented in Table 3. The effective drainage area, runoff curve number and time of concentration used to simulate the flood hydrology of McDonalds Branch are presented in Table 4. The results of the analysis are presented in Table 5. Extremely close matches were obtained for the 2- and 10-year floods.

TABLE 5

PEAK FLOOD FLOW RATES, MCDONALDS BRANCH

Method of Calculation	2-Year Flood (cfs)	10-Year Flood (cfs)	100-Year Flood (cfs)
Log Pearson Type III Statistical Analysis (USGS, 1979)	10	22.4	51.6
TR-20	10.4	21.4	38.1
Difference between computed and statistical flows	+4%	-4%	-26%

The under-estimation of the 100-year flood indicates that either of the following adjustments should be made for modeling the 100-year flood: (1) Antecedent soil moisture must be higher than the average value assumed in the analysis for the 100-year flood to be produced by a 100-year 24-hour rainfall; or (2) The effective area for direct runoff increases during extremely high magnitude rainfalls and an increase of the effective drainage area is required.

Despite the discrepancy in the estimate of the 100-year flood, the match of the 2- and 10-year floods indicates that at least for the 2- and 10-year flood range, the assumptions used in the model have resulted in an excellent replication of the natural flood characteristics of a headwater Pinelands watershed. Because the 10-year flood is used in the comparison of the development scenarios, no modifications to the hydrologic assumptions used in the computer analysis were necessary. Use of the same assumptions for the scenario basin analyses after adjusting for watershed differences is clearly justified.

Topographic and soils maps of the four scenario drainage basins are contained in Appendices 3 and 4. Basin soils data are presented in Table 3. Input data used for the four basins for each of the scenarios are contained in Appendix 5.

Land uses for the scenarios (Table 2) were selected to provide a wide range of development types for analysis. In none of the development scenarios (Scenarios 3 through 5) was all of the land in any of the drainage basins developed. The following guidelines were established:

1. No development was assumed to take place on the D hydrologic group soils because the high water tables would make that area undesirable for development. As a result, the development in each of the scenarios was limited to the remaining area of the basin.

2. For Scenario 3, development was assumed to take place evenly on all A, B and C hydrologic group soils.

3. In Scenario 4, development was assumed to take place only on A and B hydrologic group soils.

4. In Scenario 5, as much of the area of C hydrologic group soils was placed in the open space category as possible. As a result, most or all of the development occurred on the area's A and B soils.

Results of the analyses are presented in Table 6.

Peak 10-year flood rates for Biddle Branch are estimated to increase 4.6 times and 6.0 times above the existing peak for Scenarios 3 and 5, respectively. Increases of a similar magnitude occur for Cooks Branch. Pole Bridge Branch and Clarks Branch exhibit less significant impacts. Flows on Pole Bridge Branch are 3.2 and 3.6 times existing conditions for Scenarios 3 and 5, respectively. The smaller percentage increase results because the relatively high percentage of C and D soils (31%)

TABLE 6

RESULTS OF THE DRAINAGE BASIN SCENARIO ANALYSIS FOR THE 10-YEAR FLOOD

Drainage Basin	Scenario Number	Peak Discharge (cfs)	Ratio of Discharge to Discharge for Existing Locations	Total Runoff from Drainage Area (inches)	Ratio of Basin Runoff to Basin Runoff for Existing Conditions
Biddle Branch	1	37.9	---	0.33	---
	3	172	4.6	1.6	4.9
	4	47.7	1.3	0.49	1.5
	5	228	6.0	2.1	6.4
Clarks Branch	1	123	---	1.8	---
	2	47.6	0.4	0.90	0.5
	3	178	1.5	2.7	1.5
	4	132	1.1	2.1	1.2
Cooks Branch	1	63.2	---	0.39	---
	3	299	4.7	1.9	5.0
	4	118	1.9	0.82	2.1
	5	390	6.2	2.3	6.0
Pole Bridge Branch	1	97.8	---	0.78	---
	3	313	3.2	2.6	3.4
	4	217	2.2	1.9	2.4
	5	371	3.8	3.1	3.9

Source: BCM

causes existing flow rates to be higher on a unit area basis. As a result, the impact of development is slightly less severe. The relatively small increase of peak flows on Clarks Branch results because existing peak flows are high due to the large percentage of C and D soils (38%) and the existing agricultural land use.* Assuming natural forest vegetation (Scenario 2), the existing 10-year peak flow rate is 250% of the pre-development rate. Hydrographs of the flows for the scenarios are presented in Appendix 6.

The scenario analyses clearly indicate the potential impacts of conventional urban development accompanied by storm sewerage. At the present time, flood flow magnitudes are extremely low in most of the Pinelands. Improperly managed development could result in significantly higher magnitudes which would, in return, cause the type of flooding problems which plague other portions of lower central and southern New Jersey.

There are two general approaches to stormwater (storm runoff) management. The first, which is more commonly practiced, is to collect runoff which drains from storm sewers or conventional roadside ditches in stormwater detention basins. The purpose of the detention basin is to allow for a more gradual release of direct runoff into downstream areas. The second alternative is to attempt to control precipitation at or very near the site on which it fell. The goal of this alternative is to allow the water to infiltrate into the soil rather than letting it become direct runoff. Information on stormwater management techniques for each of these approaches is contained in the final section of this technical memorandum.

One significantly different impact between the two approaches must be noted. Stormwater detention ponds, when located in flood plain areas, will not decrease the volume of direct runoff generated by increases in impervious land surface and storm sewerage because the soils in these areas tend to be saturated and are unable to absorb significant amounts of additional water. The flow record of the Great Egg Harbor River Tributary at Sicklersville substantiates this conclusion.

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* Direct runoff is generally higher from agricultural use than from woodlands because the loss of the continuous layer of humus and soil compaction from agricultural use reduces the infiltration rate of a soil.

A stormwater detention pond is located approximately 500 feet upstream from the USGS streamflow recording station. All of the runoff upstream from the basin, including runoff from a large storm-sewered development and the undeveloped portions of the watershed, enter the pond, which is located on D group soils. Presumably, the pond operates in a fashion such that the peak rates of flow leaving the watershed during a storm event are no greater than the peak rates which would have left it prior to development. However, as the plots in Figure 2 indicate, it appears that the volume of direct runoff has increased significantly. As groundwater recharge decreases as direct runoff increases--and groundwater recharge is important for maintaining base and low streamflows--it can be concluded that in-stream stormwater detention ponds will have a negative effect on the maintenance of the natural hydrologic regime of a Pinelands stream.

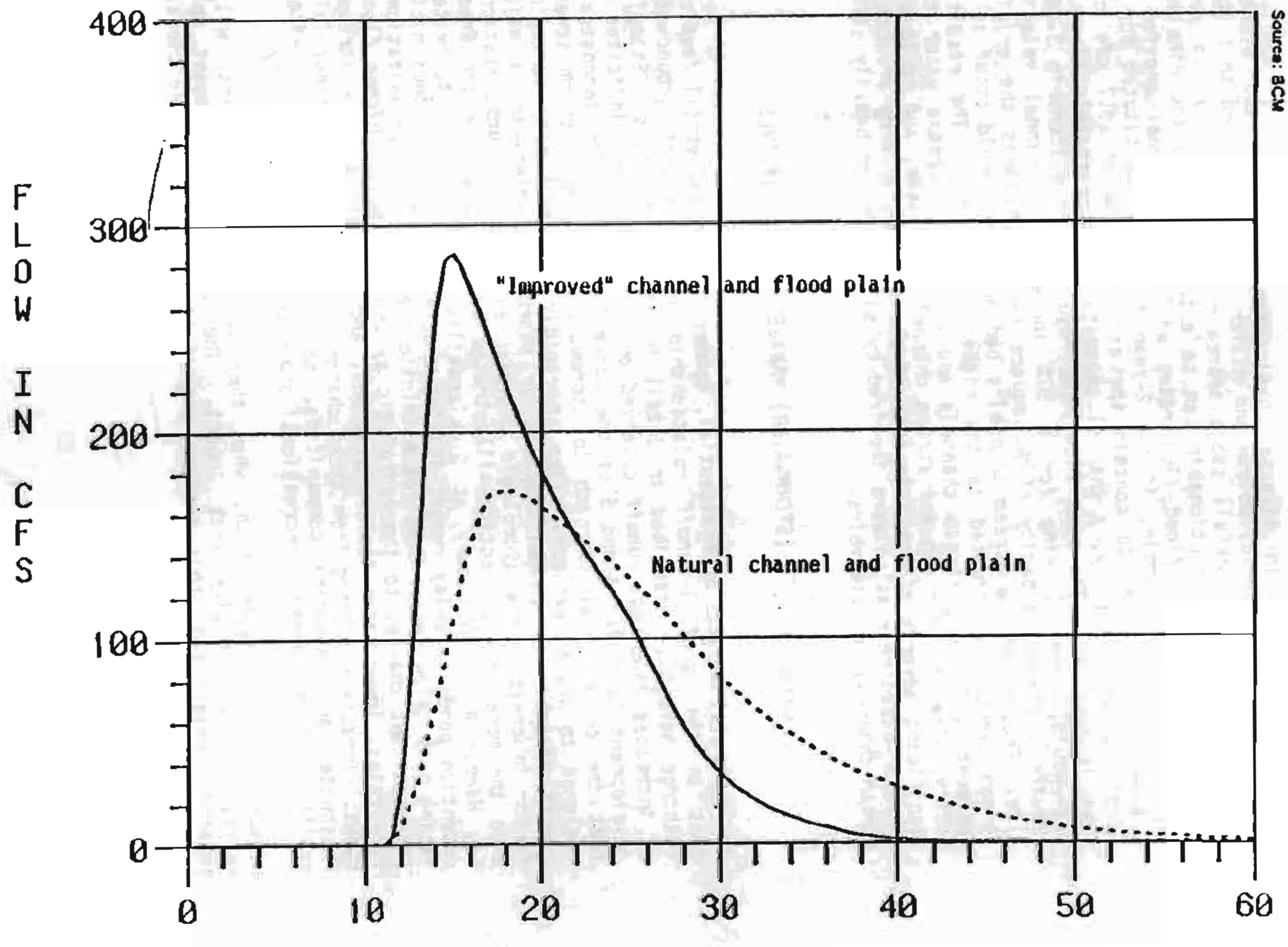
Another aspect of conventional land development practices which would have a substantial impact on peak flood flow rates is channel and/or flood plain "improvements." Within the concept of "improvements" can be included stream straightening and widening and the removal of natural vegetation. One of the reasons why flood peaks in the Pinelands are as low as they are, especially in the smaller headwater tributaries like McDonalds Branch, is because of the dense vegetation adjacent to and growing in the stream channels. The winding channels and heavy vegetation retard the velocity of flow, which results in broad, low flood peaks.

Figure 4 presents two sets of hydrographs of Biddle Branch. The hydrograph with the lower peak in each group represents the flow from Scenario 3 with no modification of the existing channels and flood plains. The second hydrograph, also based on Scenario 3 land use, presents the outflows from the basin, assuming stream "improvements" were made. The "improvements" result in a 67% increase in peak flow rates for Scenario 3.

Stream straightening, widening, or the removal of vegetation will, therefore, result in significant increases in peak flow rates, with or without watershed urbanization. An exception, where the clearance of vegetation will not have a significant impact on peak flood flows, is clearing for cranberry production. The dikes constructed to impound water for cranberry production also retard the rate of runoff during storm events.

A secondary impact of higher rates of stormwater runoff is increased streambank erosion and channel enlargement. Stream channel size is adjusted to the characteristics of drainage basin flow. Based on the

BIDDLE BRANCH - 10 YEAR - SCENARIO 3



analysis of rivers in diverse physiographic settings and differing greatly in size, Leopold, Wolman and Miller (1964) concluded that stream channels reach the bankfull stage approximately once every 1.5 years. Assuming that this relationship can be extrapolated to the Pinelands, any increase in peak flood flow rates will cause channel erosion and enlargement. For example, if the 2-year flood is substituted for the 1.5-year flood, then, to contain the existing flow of 16.7 cfs of a Biddle Branch tributary, a channel capacity of approximately 17 square feet is required. The peak flow rate resulting from Scenario 3--61.4 cfs--would, even allowing for a 50% increase in channel velocity, require a channel capacity of 41 square feet, 2.4 times the original size. Erosion of the stream channel's bed and banks would occur as the stream eventually adjusted to the higher peak flows. The resultant sediment would clog stream channels and culverts, increase water turbidity, alter flood plain and stream channel ecosystems, and could have significant adverse economic impacts if downstream cranberry production or water-based recreation were impaired by silted bogs or heavily silted stream channels or reservoirs.

DIRECT RUNOFF (STORMWATER) MANAGEMENT ALTERNATIVES

The potential impacts of residential, commercial and industrial development on the rainfall-runoff relationship and consequent groundwater recharge have been described in detail in earlier sections. Examples of increases in direct runoff observed on Long Island and indicated by development Scenarios 3 and 5 of the current investigation demonstrate that the conventional approach to stormwater management--storm sewers designed to drain developed sites as rapidly as possible by conveying runoff directly to stream channels or nearby estuaries--are a major factor in creating the hydrologic changes resulting from urbanization. Even the more recent practice--illustrated by the data from the Great Egg Harbor River Tributary at Sicklersville--of providing stormwater detention ponds to delay runoff leaving a developed site and thus mitigating peak flow rates, does not eliminate the impacts of urbanization. The resultant changes to the hydrologic system may include higher flood flow rates, lower water table elevations, and low base and low streamflows. Impacts resulting from these changes may be felt by terrestrial, freshwater and estuarine communities, may result in impaired water quality, and may decrease recreational opportunities and/or quality.

Measures are available which, when they accompany development, will result in substantially less impact. The technical management approaches presented in this section are divided into two subsections:

delay of runoff on-site and increased on-site infiltration. The principal objectives of these measures are the maintenance of direct runoff volumes and peaks from areas of urban development at or near the levels which occurred prior to development. Additionally, the measures to increase infiltration may also serve to preserve groundwater recharge rates and thereby ensure maintenance of base and low streamflow rates.

Included among the measures to be described are detention ponds, rooftop storage, parking lot storage, dutch drains, porous pavement, dry wells and recharge basins. Some methods are appropriate for single-family homes, while others are most feasible for larger complexes, such as shopping centers. Measures which are useful under certain conditions or in one type of area, will not function in others. Careful consideration must be given not only to the ability of these measures to reduce runoff quantity from development, but also to the resultant impacts on surface water and groundwater quality, costs, land requirements, maintenance needs, safety, and acceptability by the public.

The legal basis to require property owners and land developers to provide and operate stormwater management facilities must be established. The types of legislation used by local jurisdictions to control stormwater runoff from new land developments include: subdivision regulations, zoning ordinances, building codes, plumbing and sewer codes, water pollution control ordinances, flood control ordinances, and drainage fee assessment ordinances. Design specifications are required in many instances. Legal considerations for any ordinance or code may include some or all of the following: responsibility for maintenance of the stormwater management facilities; safety measures to minimize hazards from management facilities; and inspection and enforcement capabilities of local government.

Potential political problems include the modification of existing laws, codes, ordinances, regulations, etc., to include provisions for practical and effective measures for controlling on-site runoff. Two especially difficult problems are requiring special stormwater management restrictions in certain areas (e.g., areas extremely sensitive to groundwater pollution) and enforcing laws and regulations once they are established. Enforcing stormwater management requirements may include review of site development plans, construction inspection, post-construction operation inspection, and a provision for fines and penalties.

Acceptance of on-site stormwater management by individual residents, local government officials and local and outside engineers, builders and developers is essential. A public education program may be beneficial in winning public acceptance. Issues related to public acceptance include: the availability of space for construction of facilities;

costs of available measures (and reduced costs of not requiring extensive storm sewer systems in many areas); the need to build facilities to be aesthetically pleasing and compatible with the local environment; the reluctance of builders, architects and building owners to implement certain control measures such as rooftop storage; and the availability of reasonably accurate methods to determine existing and future runoff rates.

Delay of Runoff On-site*

Delay of runoff on-site generally is designed to maintain peak flow rates leaving a developing area at or near the levels which existed prior to development. These measures may be used alone or together with methods to maintain groundwater recharge.

Detention Basins: A stormwater detention basin is the most effective technique for controlling peak runoff from a large site at one point. Basins constructed on ground surfaces are usually large, having the appearance of a small pond or lake. The major design considerations are the volume of storage needed and the maximum permitted release rate. Release rates are generally a function of the capacity of the receiving stream or the maximum discharge rates prior to development. Basins can be designed to maintain a permanent pool to provide recreational or aesthetic benefits or to empty entirely following rainfall events.

Detention basins constructed on impervious or saturated soils do not provide recharge to the soil. As a result, the natural rainfall-direct runoff relationships of an area are not maintained. In addition to reducing flood peaks, the basins provide a positive impact on water quality by trapping the bed load and a portion of a stream's suspended sediment load, thereby reducing the potential impacts of development on downstream water quality.

Parking Lot Storage: Temporary storage of stormwater on parking lots or other paved areas is another means of reducing runoff rates in urbanizing areas. Advantages of this alternative include:

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* Much of the information in this subsection and the subsection on increased infiltration on-site is derived from Tourbier and Westmacott (1974).

- Unlike rooftops, there is no structural limit to the depth of water that can be stored
- The surface need not be level
- Maintenance and operation of the facility is a low-cost operation
- It can be linked with on-site infiltration measures, such as seepage pits, in order to achieve both a reduction in peak flow rate and volume of direct runoff

Problems related to the use of this measure for stormwater detention include temporary public inconvenience and tire traction during winter conditions.

There are two general approaches to parking lot detention. The first, storage of runoff in depressions constructed at drain locations, provides a minimum of inconvenience. For example, the parking lot of a shopping center can be designed so that the least-used portions of the lot serve as the major collection areas. In most cases, ponded water is designed to not exceed a depth of 12 inches and to drain within 30 minutes. A storm sewer drainage system is required, but because of the surface storage, the required pipe size will be less than it would be without parking lot storage. The other approach is to use the paved areas to channel water to seepage pits if conditions are satisfactory for infiltration. In areas where groundwater is vulnerable to contamination, consideration must be given to the quality of the stormwater runoff and its impact on the groundwater system.

Rooftop Storage: Horizontal rooftops are another area which may be used for stormwater detention. The principal advantages of this alternative are that it does not require any additional land area and it does not inconvenience pedestrians. Potential problems such as leakage, structural overloading, maintenance for removal of debris and ice, must be accounted for. Serious damage to the building and its contents could result if the facility is incorrectly designed or maintained.

A flat roof is used as a retarding pond by delaying flow or runoff to the downpipe inlet.

On sloping roofs, it is possible to slightly delay runoff by constructing very low gravel check dams. This technique is only effective for very short, high intensity storms. The potential maintenance problem is often a major argument against rooftop storage. However, all flat roofs need some maintenance to ensure clear downpipe entrances and protection against leakage. Proper design, including provision for proper overflow, can make this a feasible alternative. Rooftop storage can be linked with seepage pits or other methods of inducing infiltration of stormwater.

Infiltration of Runoff On-Site

Dutch Drains: Dutch drains are gravel-filled ditches with an optional drainage pipe in the base. They are designed to reduce both the peak rate and volume of storm runoff. The drains are designed to intercept runoff from a relatively small area, such as a rooftop or driveway, prior to concentration from a large area, or as in median strips between sections of parking lots. The measure can be used on any type of site where soil permeability is sufficiently high and where seasonally high water tables are not a factor.

The gravel-filled ditches are either designed to contain volumes of water produced by large storms or to overflow beyond a certain capacity. Potential problems include clogging of the materials surrounding the gravel.

Porous Paving--Asphalt: Porous pavement consists of a base course of crushed gravel and a surface course of porous asphalt paving. The pavement absorbs rainfall where it falls and transmits it to its gravel base. A significant advantage over conventional parking lot storage is that there is not the inconvenience of ponded water. Installed in areas of well-drained soil, so that frost-thaw cycles will not be a problem, the pavement allows for both mitigation of flood peaks and reduction in run-off volume, while maintaining groundwater recharge. To protect the operation of the infiltration features of the pavement, it should not be used in areas which may receive deposits of sediment.

Precast Lattice Blocks and Bricks: The objective of this measure is to infiltrate precipitation "at source" prior to concentration. These blocks and bricks are used over soils of high infiltration rates and can be used as parking areas, median strips, etc.

Seepage Basin or Recharge Basin: Acting somewhat similar to detention basins, recharge basins may concentrate runoff from a fairly large area. The purpose of this type of basin, however, is to allow the runoff to recharge the groundwater system. Recharge basins have been used extensively on Long Island to recharge groundwater. Contamination of groundwater is a potential hazard of retention basins in areas draining large amounts of high density urban land. As a result, basins should not be constructed in areas where the recharged water will be withdrawn for water supply, unless analyses are conducted to determine the potential impact of the infiltrated water on groundwater quality.

<u>Seepage Pits or Dry Wells</u>: Seepage pits and dry wells operate under the same principle as recharge basins--by collecting runoff and storing it until it percolates into the soil. However, they typically are used for much smaller drainage areas. Seepage pits can be used in all areas with high infiltration rates. They may be designed to accommodate large runoff from large storms. If designed properly and connected to the on-site source areas of direct runoff, they can preserve the rate and volume of runoff at pre-development levels.

<u>Seepage Beds</u>: Seepage beds dispose of runoff by infiltration into a soil via a system of drains set in ditches of gravel. The beds provide for the distribution of water over a larger area than may be achieved by a seepage pit. They may be placed under areas of paving. Sediment traps upstream from the distribution system may be necessary to prevent clogging. A summary of the various techniques is presented in Table 7.

IMPACT OF WATER SUPPLY AND WASTEWATER TREATMENT ON STREAMFLOW QUANTITY

Water withdrawn for individual or small community water supply can have little or significant impact on streamflow. If wastewater is discharged directly to on-site treatment systems which allow the water to infiltrate into the soil, reductions of streamflow will be minor. However, if wastewater is exported via sanitary sewers to areas downstream or to another watershed for treatment, local streamflow may decrease significantly. An example of the potential impact is described below.

Assume one-acre density development occurs in a headwaters tributary similar to McDonalds Branch and assume water use of 100 gallons per day per capita and 3.5 persons per household. Annual water use would be approximately 127,800 gallons/acre or 16,990 cubic feet per acre. This is the equivalent of 4.7 inches of water spread over the entire acre. If it is assumed that the entire amount of well water would have become streamflow, and if the entire amount of wastewater is exported for treatment, then if streamflow was equivalent to 13.6 inches of runoff (average annual discharge from McDonalds Branch), the post-development runoff would be approximately 8.9 inches, a reduction of 35 percent. This would significantly reduce base and low flows.

TABLE 7

SUMMARY OF STORMWATER MANAGEMENT TECHNIQUES

Management Technique	Objective: Reduce Peak Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Advantages	Disadvantages
Detention Ponds					
1. With a normal pool	X		Usually a earthen basin with a minimum pool of water at all times; outlet structure regulates outflow from the basin.	1. Can be used with a large tributary area 2. Highly effective for reducing peak flow rates 3. May have aesthetic or recreational benefits 4. Supplemental firewater source 5. Reduces suspended sediment load	1. Does not allow for significant infiltration 2. Can become a mosquito breeding ground 3. Considerable amount of land is required 4. Potential safety hazard unless properly secured
2. Without a normal pool	X		Usually an earthen basin which is dry between periods of precipitation; outlet structure regulates outflow from the basin.	1. Can be used with a large tributary area 2. Highly effective for reducing peak flow rates 3. Reduces suspended sediment load	1. Does not allow for significant infiltration 2. Can become a mosquito breeding ground 3. May become unsightly 4. Potential safety hazard unless properly secured
Parking Lot Storage	X		In large parking areas, typically a portion of the lot which is least frequently used; outflow structures are constructed in order to temporarily pond water.	1. Requires no additional area 2. No structural limit on depth of storage 3. Does not need to be level 4. May be combined with dutch drains or other seepage techniques and vegetated buffer ditches	1. Temporary inconvenience to car owners 2. Ice formation 3. Potential groundwater pollution source when combined with subsurface seepage techniques 4. Detention time insufficiently long for Pinelands area
Rooftop Storage					
1. Flat rooftops	X		Perforated strainers or gravel barriers surround downpipe inlets to regulate outflow	1. Requires no additional area 2. May be combined with dutch drains or other seepage techniques and vegetated buffer ditches 3. Reduced air conditioning expense	1. Increased roof loads 2. Leakage potential increased 3. Additional maintenance required

TABLE 7 (Continued)

Management Technique	Objective: Reduce Peak Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Advantages	Disadvantages
Rooftop Storage (Continued)					
2. Sloping rooftops	X		Gravel check drains retard flow velocity and temporarily pond small amounts of water	1. Requires no additional area 2. May be combined with dutch drains or other seepage techniques and vegetated buffer ditches	1. Only minor reduction of peak flows 2. Increased leakage potential 3. Increased maintenance required
Dutch Drains	X	X	Gravel-filled ditches with an optional drainage pipe pipe at the base. May be covered by lattice blocks or steel grate	1. Maintains groundwater recharge 2. Provides water for vegetated buffer strips 3. Small surface area	1. Subject to clogging 2. May be unable to contain runoff from exceptional storms 3. Potential for ground-, water pollution
Porous Paving					
1. Asphalt	X	X	Base course of crushed gravel with a surface course of porous asphalt paving	1. No additional land required 2. Maintain groundwater recharge 3. Water is not stored on surface	1. Should not be used where excessive surface debris may clog pores 2. Potential for groundwater pollution 3. Cannot be used over seasonally high water tables
2. Precast lattice blocks and bricks	X	X	Precast paving slabs which provide a hard surface and yet are porous to varying degrees	1. Flexible 2. Can be used between strips of impervious asphalt	1. Difficult and expensive to install 2. Not as permeable as porous asphalt
Seepage Basin or Recharge Basin	X	X	Similar to detention basins but constructed in in areas of low water tables and high infiltration rates; generally do not have outflow structures	1. Increased recharge of groundwater	1. Basin may loose recharge efficiency due to clogging 2. Potential for groundwater pollution
Seepage Pits or Dry Wells	X	X	Similar in concept, but for smaller areas than recharge basins	1. Increased recharge of groundwater	1. Possibility of clogging; may need maintenance
Seepage Beds	X	X	Similar to seepage pits, but with addition of lateral distribution pipes	1. Increased recharge of groundwater 2. Clogging potential is less than with seepage pits due to larger area 3. May be used under parking lots	1. Clogging potential

TABLE 7 (Continued)

Management Technique	Objective: Reduce Peak Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Appropriate Development	Potential Appropriate Portion of the Pinelands
Detention Ponds					
1. With a normal pool	X		Usually a earthen basin with a minimum pool of water at all times; outlet structure regulates outflow from the basin.	1. High density residential 2. Commercial and industrial areas	1. Areas with seasonally high water tables 2. Areas where recharge is less important
2. Without a normal pool	X		Usually an earthen basin which is dry between periods of precipitation; outlet structure regulates outflow from the basin.	1. High density residential 2. Commercial and industrial areas	1. Areas where recharge is less important
Parking Lot Storage	X		In large parking areas, typically a portion of the lot which is least frequently used; outflow structures are constructed in order to temporarily pond water	1. High density residential 2. Commercial and industrial areas	1. Areas where recharge is unimportant 2. Areas underlain by loamy soils (if combined with subsurface seepage)
Rooftop Storage					
1. Flat rooftops	X		Perforated strainers or gravel barriers surround downpipe inlets to regulate outflow	1. Large buildings	1. Areas where recharge unimportant unless combined with subsurface seepage
2. Sloping rooftops	X		Gravel check drains retard flow velocity and temporarily pond small amounts of water	1. Small buildings	1. Areas where recharge unimportant unless combined with subsurface seepage
Dutch Drains	X	X	Gravel-filled ditches with an optional drainage pipe pipe at the base. May be covered by lattice blocks or steel grate	1. Individual residences, small buildings and parking lots	1. Medium and low density residential; lightly used road shoulders

TABLE 7 (Continued)

Management Technique	Objective: Reduce Peak Rate of Runoff	Objective: Reduce Volume of Runoff	Description	Appropriate Development	Potential Appropriate Portion of the Pinelands
Porous Paving					
1. Asphalt	X	X	Base course of crushed gravel with a surface course of porous asphalt paving	1. Residential, commercial or light industrial parking areas	1. All areas of high infiltration rates if concentration of pollution sources is low
2. Precast lattice blocks and bricks	X	X	Precast paving slabs which provide a hard surface and yet are porous to varying degrees	1. All types of development for small ground areas	1. All areas of development
Seepage Basin or Recharge Basin	X	X	Similar to detention basins but constructed in in areas of low water tables and high infiltration rates; generally do not have outflow structures	1. All types of development	1. Areas where reduction in groundwater quality will not pose problems
Seepage Pits or Dry Wells	X	X	Similar in concept, but for smaller areas than recharge basins	1. Individual home sites in single or cluster development; small buildings	1. All areas with sufficiently low water tables
Seepage Beds	X	X	Similar to seepage pits, but with addition of lateral distribution pipes	1. Individual home sites in single or cluster development; small buildings	1. All areas with sufficiently low water tables

Source: Betz-Converse-Murdoch-Inc.

SUMMARY

Documentation demonstrates that, in many parts of the United States, including Long Island, NY, which shares many hydrologic similarities with the Pinelands, increased urbanization can lead to increased peak flood flow rates and higher percentages of direct runoff. An analysis of streamflow records of the Great Egg Harbor Tributary at Sicklersville, located adjacent to the boundary of the Pinelands National Reserve, indicates that residential development has increased the volume of direct runoff resulting from rainfall events.

An analysis of hypothetical development scenarios on four Pinelands drainage basins indicated that without stormwater management, peak flood flow rates will increase significantly. As the percentage of direct runoff from rainfall increases with development, recharge to the groundwater reservoir decreases. Because most of base streamflow is derived from discharge from the groundwater reservoir, any decrease in recharge to the reservoir will lower base streamflows.

In-stream stormwater detention ponds, such as the one located on the Great Egg Harbor Tributary at Sicklersville, are not likely to maintain existing direct runoff relationships. Therefore, this type of stormwater management device should not be recommended where recharge to the groundwater reservoir and maintenance of existing base and low streamflow are required.

Stream channel "improvements," which may accompany development, can have a significant impact on flood flow rates. A computer analysis indicated that, by reducing natural channel and flood plain retardance, peak flood flow rates significantly increased.

An additional impact of higher peak runoff rates is channel erosion and enlargement. Sediment resulting from channel erosion may have significant adverse impacts on aquatic and terrestrial communities, cranberry production, and water-based recreation.

Several alternative techniques are available to manage stormwater runoff from urbanizing areas. The two approaches are those which delay runoff on-site and those which allow rainfall to infiltrate to reduce direct runoff.

APPENDIX 1

DESCRIPTION OF THE HYDROLOGIC SOIL GROUPS

APPENDIX 1

DESCRIPTION OF THE HYDROLOGIC SOIL GROUPS

The hydrologic soil groups are defined as (SCS National Engineering Handbook, Section 4, Hydrology, 1972):

"A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

"B. Soils have moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

"C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

"D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission."

APPENDIX 2

MODIFIED DIMENSIONLESS HYDROGRAPH

4 DIMHYD		0.02			
8	.000	.111	.356	.655	.896
8	1.000	.929	.828	.737	.656
8	0.584	.521	.465	.415	.371
8	.331	.296	.265	.237	.212
8	.190	.170	.153	.138	.123
8	.109	.097	0.86	.076	.066
8	.057	.049	.041	.033	.027
8	.024	.021	.018	.015	.013
8	.012	.011	.009	.008	.008
8	.006	.006	.005	.005	.000
9 ENDTBL					

Source: Soil Conservation Service, 1980

APPENDIX 3

TOPOGRAPHIC MAPS OF THE FOUR SCENARIO DRAINAGE BASINS AND MCDONALDS BRANCH

APPENDIX 4

SOILS MAPS OF THE FOUR SCENARIO DRAINAGE BASINS AND MCDONALDS BRANCH

APPENDIX 5

INPUT DATA FOR TR-20 COMPUTER MODELS OF SCENARIO DRAINAGE BASINS

TABLE 5-1

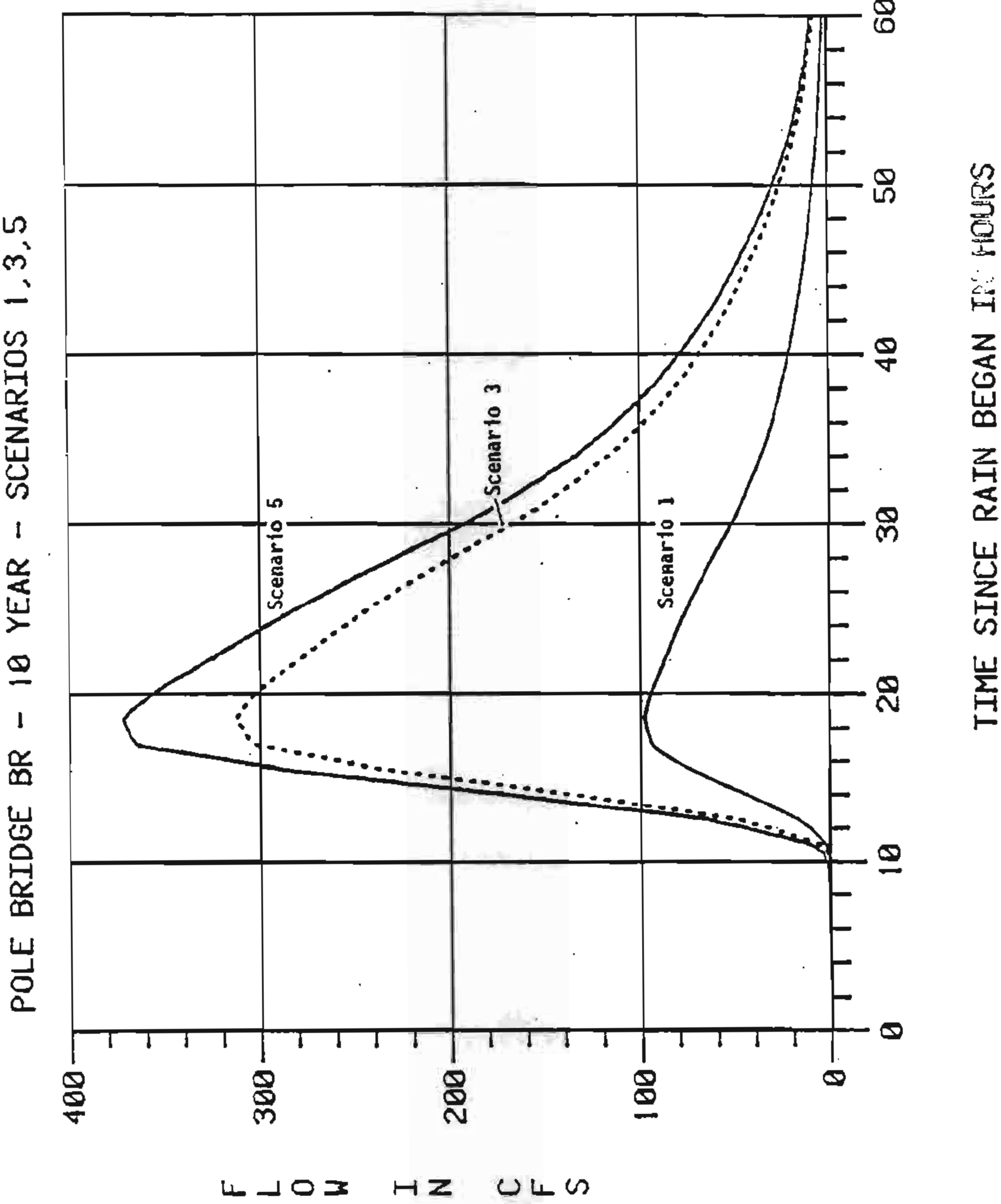
INPUT DATA FOR TR-20 COMPUTER MODELS OF SCENARIO DRAINAGE BASINS

Drainage Basin	Scenarios	Effective Drainage Area (square miles)	Runoff Curve Number	Time of Concentration (hours)
Biddle Branch	1	.38	72	7.08
Clarks Branch	1	1.43	74	9.66
Cooks Branch	1	.51	74	6.05
Pole Bridge Branch	1	1.09	74	8.91
Clarks Branch	2	.75	71	11.97
Biddle Branch	3	2.78	62	7.55
Clarks Branch	3	1.95	75	9.24
Cooks Branch	3	3.40	66	6.13
Pole Bridge Branch	3	3.51	74	9.04
Biddle Branch	4	2.78	44	7.08
Clark Branch	4	1.95	68	9.66
Cooks Branch	4	3.58	50	6.05
Pole Bridge Branch	4	3.51	65	8.91
Biddle Branch	5	2.78	68	7.55
Cooks Branch	5	3.4	71	6.13
Pole Bridge Branch	5	3.51	79	9.04

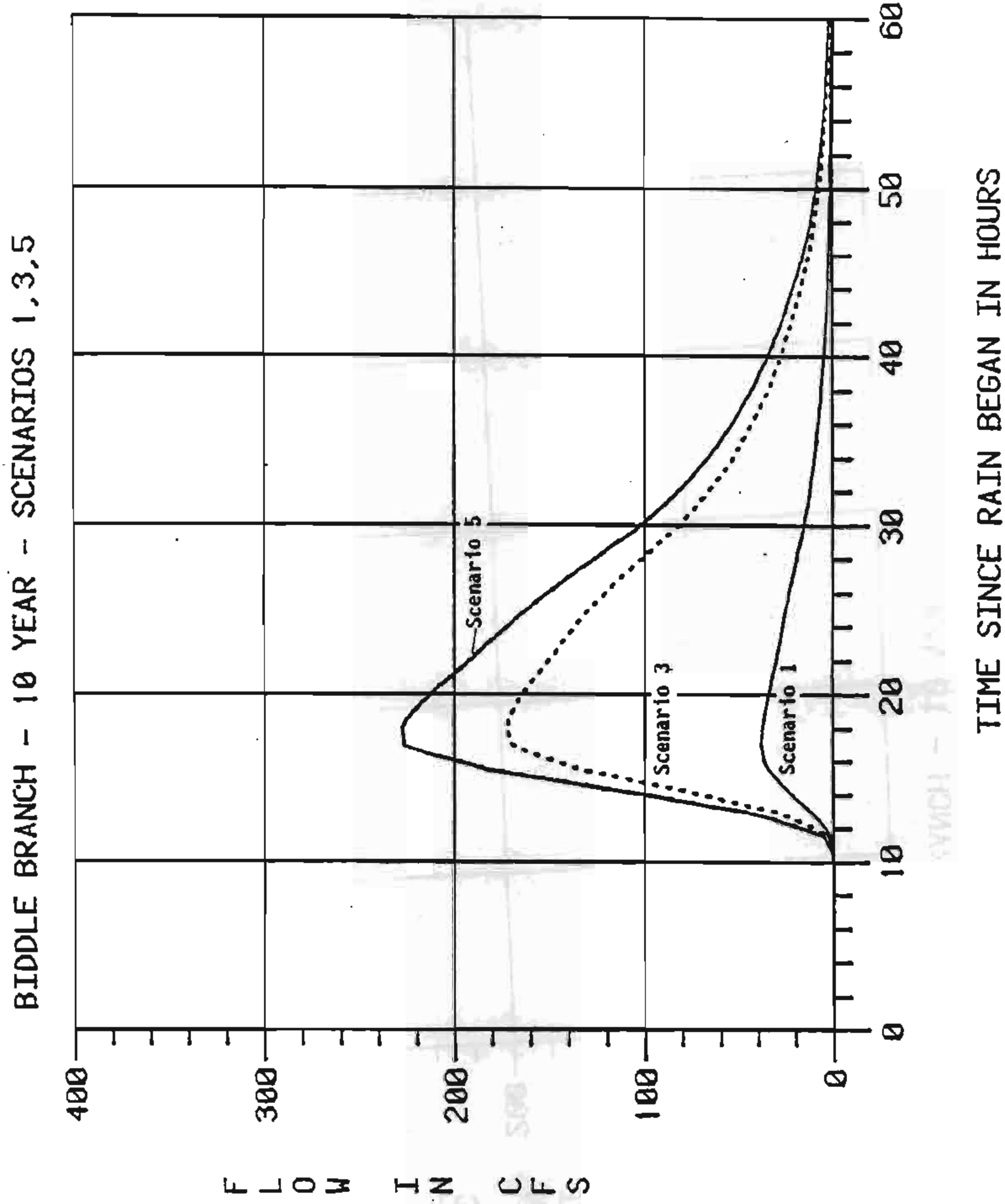
APPENDIX 6

HYDROGRAPHS OF SCENARIOS 1, 3 AND 5

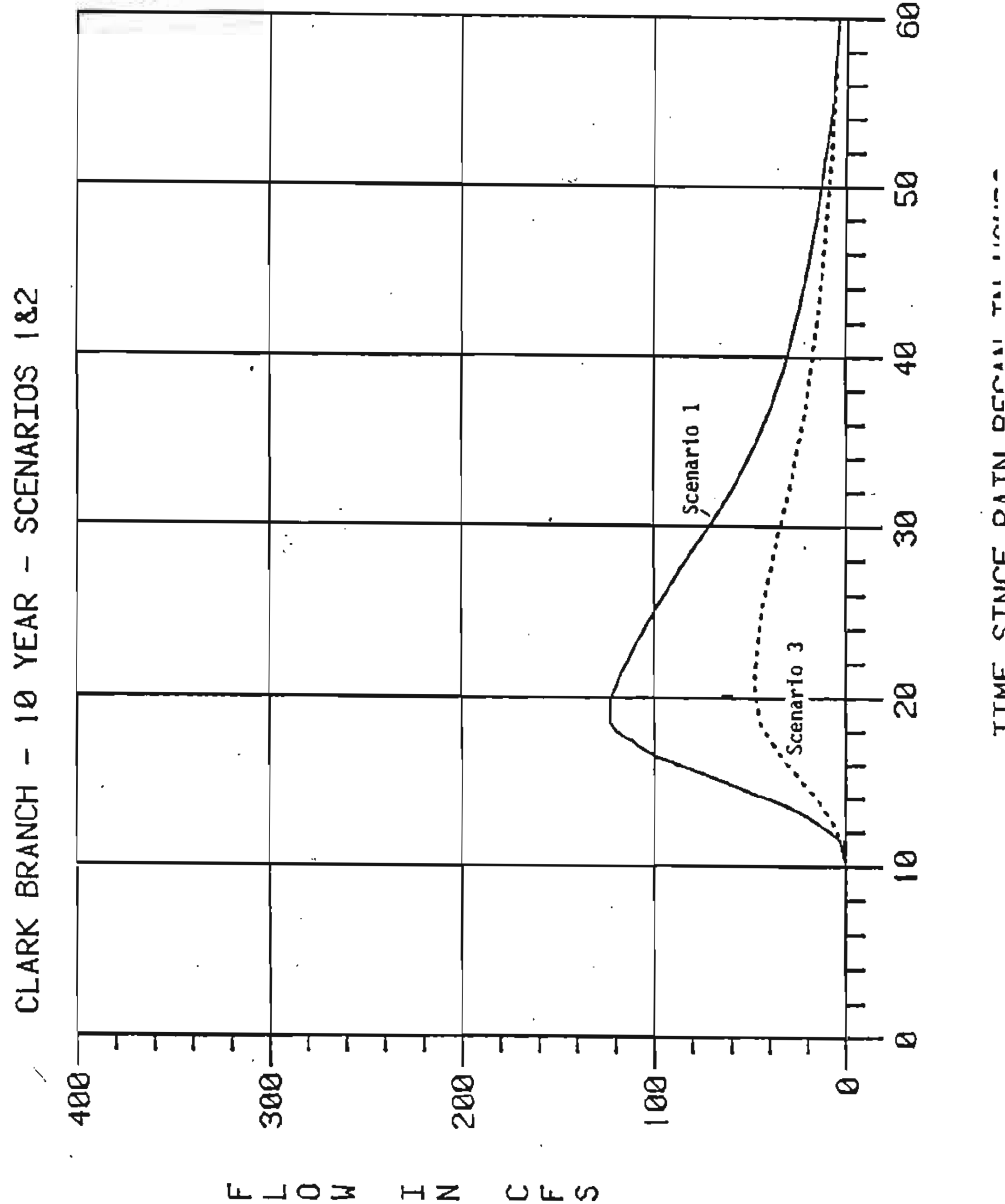
Source: BCM


POLE BRIDGE BR - 10 YEAR - SCENARIOS 1,3,5
Scenario 5
Scenario 3
Scenario 1
TIME SINCE RAIN BEGAN IN HOURS
0
10
20
30
40
50
60
FLOW IN CFS
400
300
200
100
0

Source: BCM


BIDDLE BRANCH - 10 YEAR - SCENARIOS 1,3,5
Scenario 5
Scenario 3
Scenario 1
TIME SINCE RAIN BEGAN IN HOURS
0
10
20
30
40
50
60
FLOW IN CFS
0
100
200
300
400

Source: BCM


CLARK BRANCH - 10 YEAR - SCENARIOS 1&2
Scenario 1
Scenario 3
0
10
20
30
40
50
60
0
100
200
300
400
FLOW IN CFS