DEPTH - LEVEL - FLOW RELATIONSHIP OF THE SUSQUEHANNA RIVER AT THE SUSQUEHANNA SES ENVIRONMENTAL LABORATORY

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This report addresses the relationship between level (ft above msl) and flow (cfs) of the Susquehanna River at the Susquehanna SES Environmental Laboratory. Due to the distance from established gaging stations, the frequency of droughts, and the increasing demand for water from the river, a reliable estimate of river flow is necessary at the Susquehanna Steam Electric Station. Flow can either be determined directly at a specific cross section or calculated from mathematical models based on the level-flow relationship.

A database of river level and flow has been maintained at the Susquehanna SES Environmental Laboratory since 1973. Level was monitored using a continuous recording depth gage. Flow was calculated from U. S. Geological Survey (USGS) data at the Wilkes-Barre and Danville gaging stations using the formula:

$$River\ flow = 0.222(a - b) + b$$

where a and b are mean daily flows at Danville and Wilkes-Barre, respectively. The model was based on the difference in flow between the gaging stations and the additional drainage area from Wilkes-Barre to the laboratory. This equation was inconvenient to use because it required data from the USGS in Harrisburg, PA where there was a time lag of approximately five or six months between the end of the USGS water year and their final data report. In addition, the equation only solves for daily mean river flow rather than instantaneous flow.

In 1977, we established our first computer-generated relationship between level and flow. The database consisted of daily mean level and flow data collected from July 1973 through December 1976 (Attachment 1). There was a flood point in the database, but there were no drought data. The polynomial regression equation we used was consistent with USGS data in 1977 and 1978, but in both of those years, there was an above average flow of water in the river (Attachment 2). We found the model to be inaccurate during the low flow periods of 1979 and 1980, giving estimates that were much lower than the USGS data. The units were in meters because in the 1970's the scientific community was attempting to change from the English to the metric system.

In 1981, we updated the model with data through November 1980 (Attachment 3). We hoped to improve the precision of low flow estimates with the inclusion of three more years of data, particularly with the low flow data. This model was used through 1987. A severe drought occurred during the summer of 1988 which again showed the inaccuracy of the model at low flow. Even though we had more data, the model did not explain the level-flow relationship when flow was ≤ 1000 cfs at the Wilkes-Barre gaging station. At this time, we decided to measure low river flows near the laboratory to determine the low level-flow relationship.

If drought conditions occur, the Susquehanna River Basin Commission (SRBC) has the authority to release water from the Cowanesque Reservoir to supplement river flow. This release is initiated by a flow of ≤ 868 cfs at the USGS Wilkes-Barre gaging station. Cowanesque is located along the Pennsylvania-New York border and discharges to the Chemung River. It is approximately 170 river miles upstream from the Susquehanna SES. There are 16,000 acre-feet of water available at a discharge rate of 50 - 100 cfs.

During the drought in 1988, a transect was set up approximately 900 ft upstream from the laboratory across which we were able to conduct our study (Attachment 4). Our goal was to collect flow data when the river level was < 487 ft above msl. The river was constricted to a narrow channel with no back current at these low levels. Flow was calculated from the surface area and velocity of the river cross section at the transect. A level of zero flow was also established. During August, September, and October, we made three separate flow measurements. Our measurements were comparable to the USGS flows for Wilkes-Barre and Danville. However, the drought ended and job priorities left the study incomplete. Flow calculation at the laboratory was relegated to the initial model of 1973.

When we were not able to collect any more low flow data, work focused on the USGS flow database. During our 16 years of data acquisition, the computers, computer format, and the software programs changed completely so we had to re-input data to our new system. The use of metric units in measuring flow had not gained acceptance so we converted the data to English units. We compiled these data from 1988 back to 1976, eliminated data when the river was ice covered, and established a new level-flow relationship (Attachment 5):

$$Flow = 319.96989(level)^2 - 309316.24395(level) + 74753300$$

Unfortunately, this relationship also did not work at flows less than 1000 cfs.

Another drought occurred during the summer of 1991. River level and flow at the laboratory were the lowest observed since the start of the project in 1971. The SRBC authorized the release of Cowanesque Reservoir water on 9 September. The initial release was 80 cfs and later cut back to 60 cfs. The lowest level we observed was 485.69 ft above msl on 13 September. We were able to measure flow across the transect on three separate days, and to complete a new model for river flow less than 1000 cfs (Attachment 6):

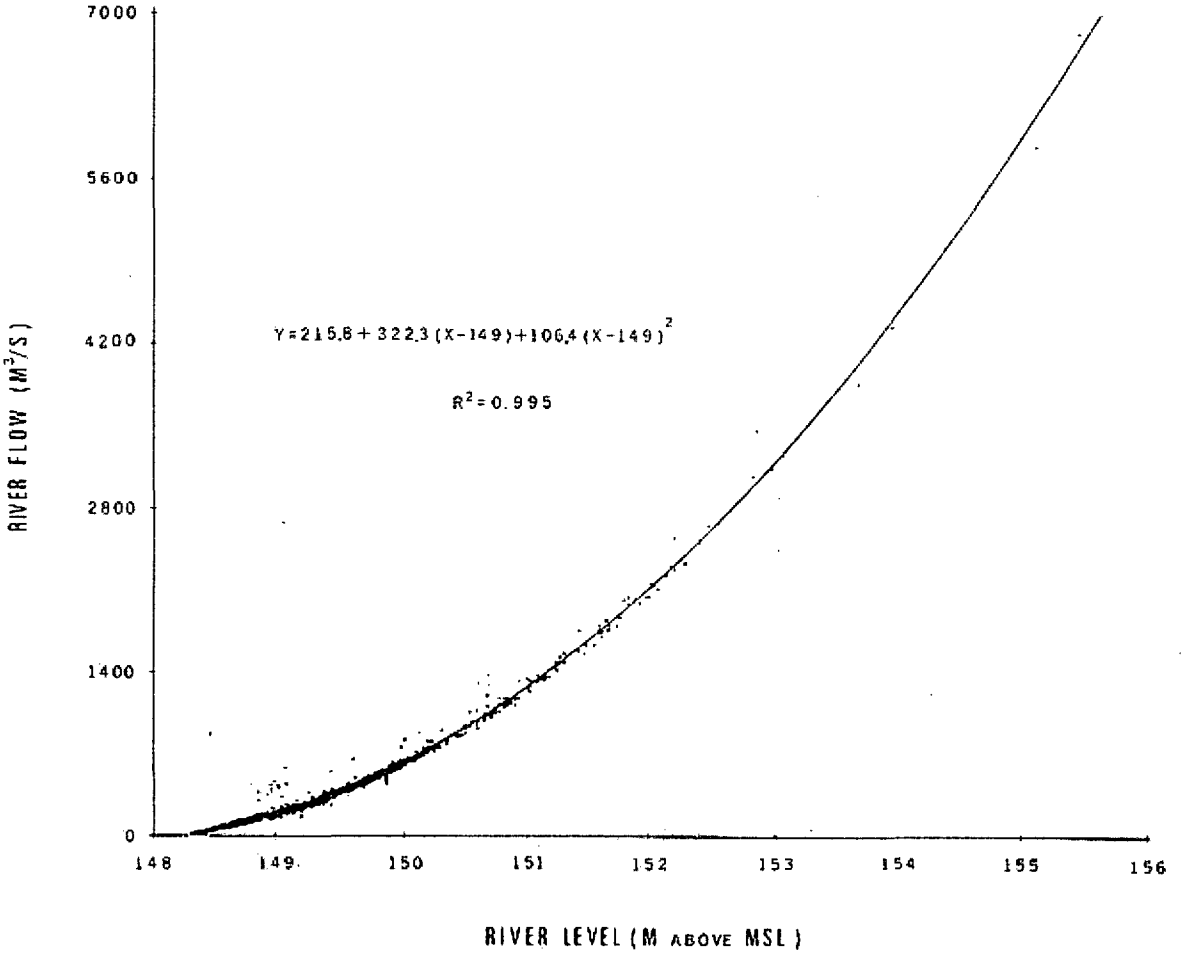
$$logFlow = - 0.05251(level)^2 + 51.478501(level) - 12612.85672$$

This model was based completely on measured flows and the point of zero flow at the transect.

Using this low flow model for levels < 486.0 ft above msl and the 1976-88 USGS data model for levels ≥ 486.0 ft, we were able to complete a table which details the level-flow relationship for the river (Attachment 7). For any observed river depth at the Susquehanna SES Environmental Laboratory, a corresponding river level and flow can be calculated. A flow range was also added to this table to further show expected variation, since depths read from the gage at the laboratory are not easily interpolated to a tenth of a foot.

This level - flow table should better explain flows at the Susquehanna SES Environmental Laboratory than previous models. We will continue to monitor USGS data to check the reliability of our two models and possibly add more data to the linear regression as it becomes available. If another drought occurs, we will measure river flow at the transect to check established data, and to add data points to the low flow model. There are no data points for levels < 485.72 ft above msl, and there is little chance of ever measuring flows for these levels since the Susquehanna River flow will be augmented by Cowanesque Reservoir flow at this time.

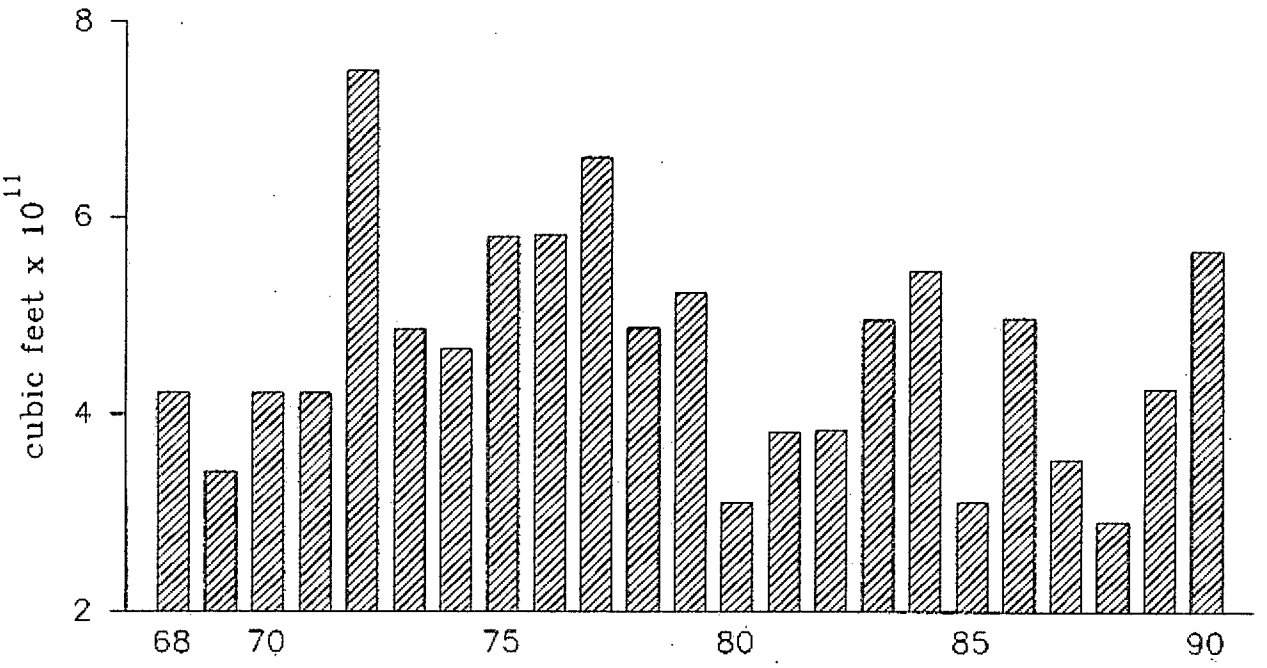
Attachment 1



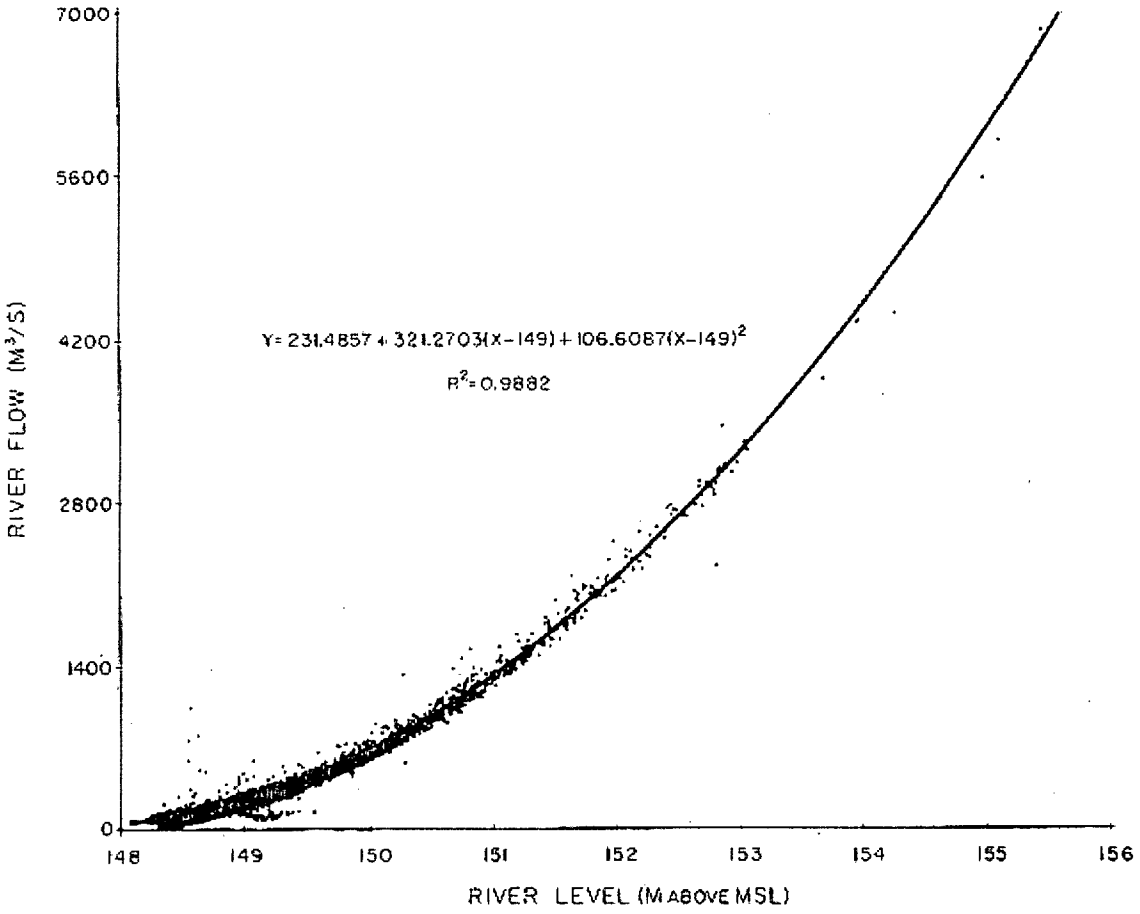
The relationship between flow (m^3/s) and level (m above msl) of the Susquehanna River at Ichthyological Associates Laboratory from July 1973 through December 1976.

Attachment 2

VOLUME OF SUSQUEHANNA RIVER FLOW
PAST THE SUSQUEHANNA SES ENVIRONMENTAL LABORATORY
1968 – 1990



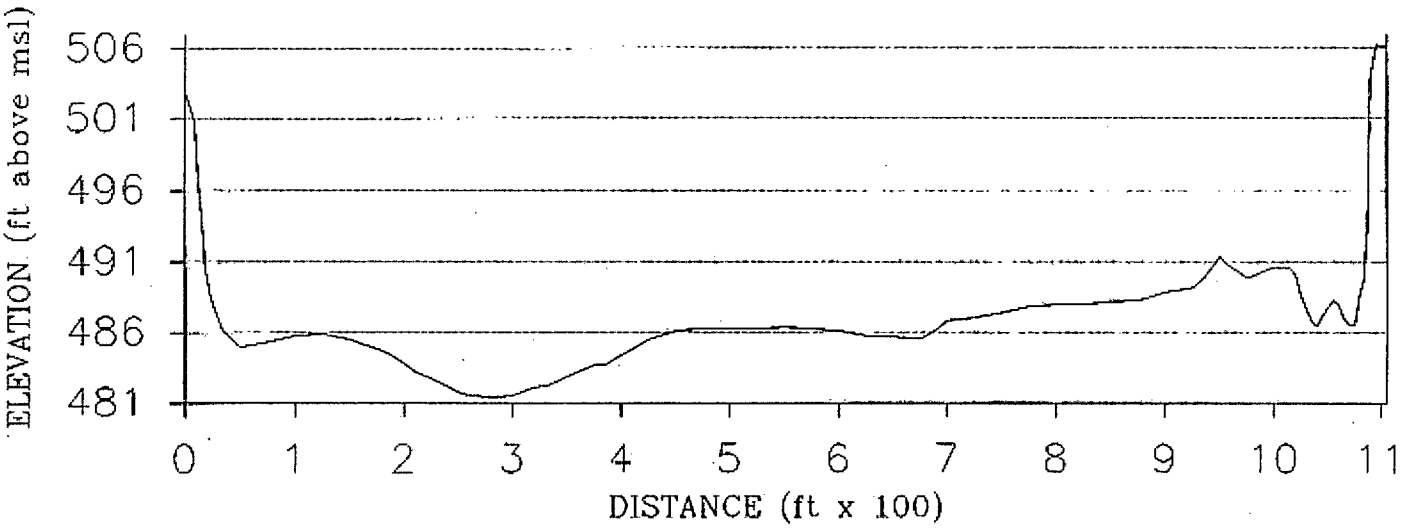
Attachment 3



The relationship between flow (m^3/s) and level (m above msl) of the Susquehanna River at the Susquehanna SES Biological Laboratory from July 1973 through November 1980.

Attachment 4

CROSS SECTION OF THE SUSQUEHANNA RIVER AT TRANSECT 1,
900 FT UPRIVER FROM THE SUSQUEHANNA SES ENVIRONMENTAL LABORATORY

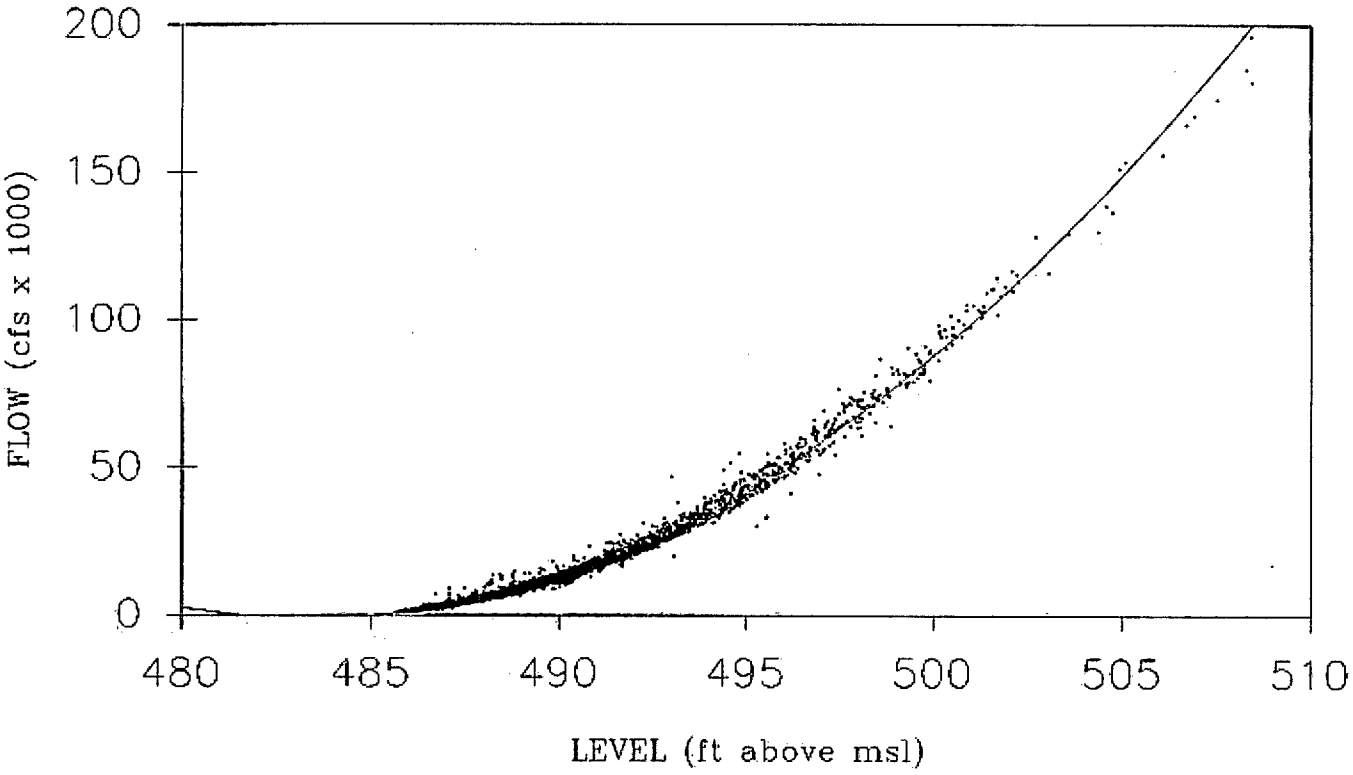


Attachment 5

LEVEL–FLOW RELATIONSHIP OF THE SUSQUEHANNA RIVER AT THE SUSQUEHANNA SES ENVIRONMENTAL LABORATORY, 1976–1988

$FLOW = 319.96989(LEVEL)^2 - 309316.24395(LEVEL) + 74753300$

$r = 0.99604$

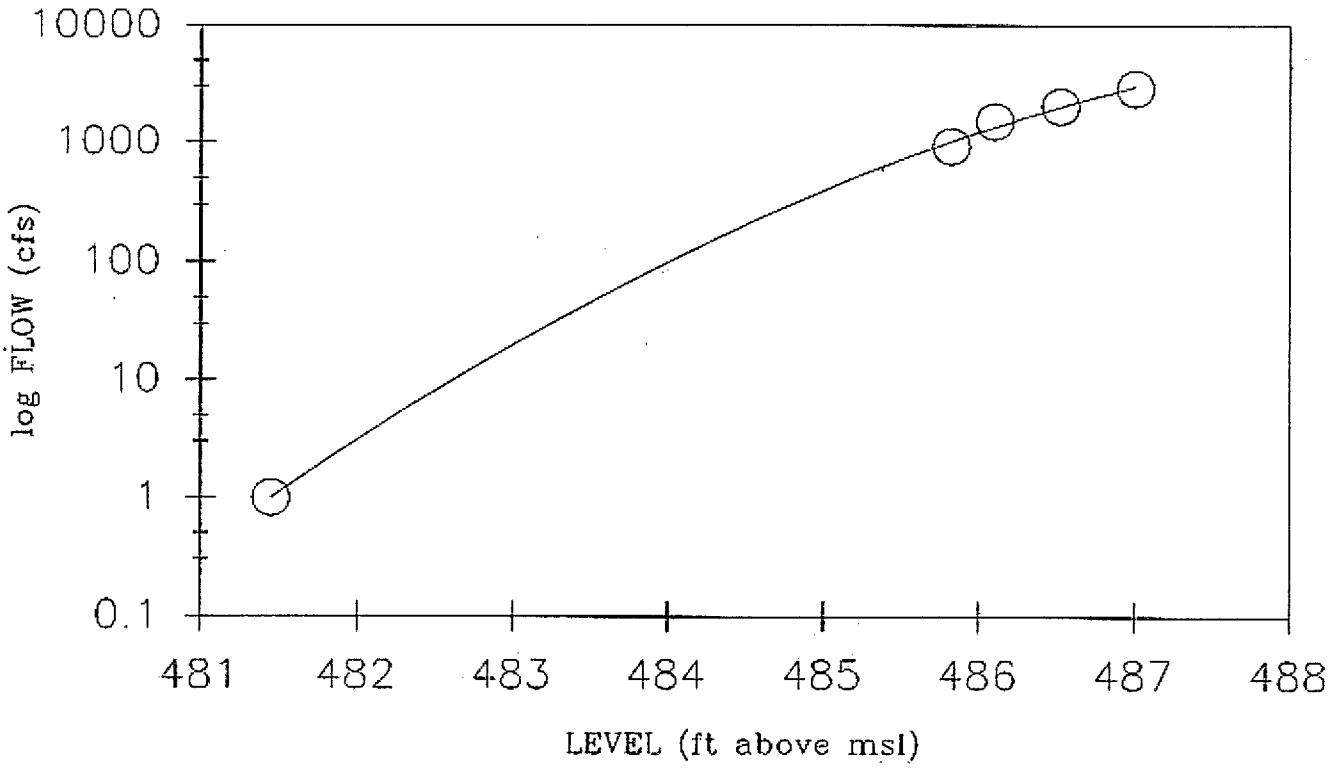


Attachment 6

LOW LEVEL–FLOW RELATIONSHIP OF THE SUSQUEHANNA RIVER
AT THE SUSQUEHANNA SES ENVIRONMENTAL LABORATORY

$$\log \text{FLOW} = -0.05251(\text{LEVEL})^2 + 51.478501(\text{LEVEL}) - 12612.85672$$

$r = 0.99978$



SEP 1991

DEPTH - LEVEL - FLOW relationship of the Susquehanna River at the Susquehanna SES Environmental Laboratory.

DEPTH (ft)	LEVEL (ft above msl)	FLOW (cfs)	FLOW RANGE (cfs)	DEPTH (ft)	LEVEL (ft above msl)	FLOW (cfs)	FLOW RANGE (cfs)	DEPTH (ft)	LEVEL (ft above msl)	FLOW (cfs)	FLOW RANGE (cfs)
2.1	485.1	403	379–428	6.1	489.1	9540	9358–9726	10.1	493.1	29370	29100–29700
2.2	485.2	455	428–483	6.2	489.2	9910	9726–10100	10.2	493.2	30000	29700–30300
2.3	485.3	513	483–544	6.3	489.3	10290	10100–10500	10.3	493.3	30630	30300–31000
2.4	485.4	576	544–610	6.4	489.4	10670	10500–10900	10.4	493.4	31270	31000–31600
2.5	485.5	646	610–683	6.5	489.5	11060	10900–11300	10.5	493.5	31920	31600–32200
2.6	485.6	723	683–763	6.6	489.6	11460	11300–11700	10.6	493.6	32570	32200–32900
2.7	485.7	806	763–851	6.7	489.7	11860	11700–12100	10.7	493.7	33230	32900–33600
2.8	485.8	897	851–946	6.8	489.8	12270	12100–12500	10.8	493.8	33900	33600–34200
2.9	485.9	1000	946–1050	6.9	489.9	12690	12500–12900	10.9	493.9	34570	34200–34900
3.0	486.0	1210	1050–1300	7.0	490.0	13110	12900–13300	11.0	494.0	35250	34900–35600
3.1	486.1	1390	1300–1480	7.1	490.1	13540	13300–13800	11.1	494.1	35930	35600–36300
3.2	486.2	1570	1480–1660	7.2	490.2	13970	13800–14200	11.2	494.2	36620	36300–37000
3.3	486.3	1750	1660–1850	7.3	490.3	14420	14200–14600	11.3	494.3	37320	37000–37700
3.4	486.4	1940	1850–2040	7.4	490.4	14860	14600–15100	11.4	494.4	38020	37700–38400
3.5	486.5	2140	2040–2240	7.5	490.5	15320	15100–15500	11.5	494.5	38730	38400–39100
3.6	486.6	2350	2240–2450	7.6	490.6	15780	15500–16000	11.6	494.6	39450	39100–39800
3.7	486.7	2560	2450–2660	7.7	490.7	16250	16000–16500	11.7	494.7	40170	39800–40500
3.8	486.8	2770	2660–2880	7.8	490.8	16720	16500–17000	11.8	494.8	40900	40500–41300
3.9	486.9	3000	2880–3110	7.9	490.9	17200	17000–17400	11.9	494.9	41640	41300–42000
4.0	487.0	3230	3110–3350	8.0	491.0	17690	17400–17900	12.0	495.0	42380	42000–42800
4.1	487.1	3460	3350–3580	8.1	491.1	18180	17900–18400	12.1	495.1	43130	42800–43500
4.2	487.2	3710	3580–3830	8.2	491.2	18680	18400–18900	12.2	495.2	43890	43500–44300
4.3	487.3	3960	3830–4080	8.3	491.3	19180	18900–19400	12.3	495.3	44650	44300–45000
4.4	487.4	4210	4080–4340	8.4	491.4	19690	19400–20000	12.4	495.4	45410	45000–45800
4.5	487.5	4480	4340–4610	8.5	491.5	20210	20000–20500	12.5	495.5	46190	45800–46600
4.6	487.6	4740	4610–4880	8.6	491.6	20740	20500–21000	12.6	495.6	46970	46600–47400
4.7	487.7	5020	4880–5160	8.7	491.7	21270	21000–21500	12.7	495.7	47760	47400–48200
4.8	487.8	5300	5160–5440	8.8	491.8	21810	21500–22100	12.8	495.8	48550	48200–48900
4.9	487.9	5590	5440–5740	8.9	491.9	22350	22100–22600	12.9	495.9	49350	48900–49800
5.0	488.0	5880	5740–6030	9.0	492.0	22900	22600–23200	13.0	496.0	50160	49800–50600
5.1	488.1	6180	6030–6340	9.1	492.1	23460	23200–23700	13.1	496.1	50970	50600–51400
5.2	488.2	6490	6340–6650	9.2	492.2	24020	23700–24300	13.2	496.2	51790	51400–52200
5.3	488.3	6800	6650–6960	9.3	492.3	24590	24300–24900	13.3	496.3	52610	52200–53000
5.4	488.4	7120	6960–7290	9.4	492.4	25160	24900–25500	13.4	496.4	53440	53000–53900
5.5	488.5	7450	7290–7620	9.5	492.5	25750	25500–26000	13.5	496.5	54280	53900–54700
5.6	488.6	7780	7620–7950	9.6	492.6	26340	26000–26600	13.6	496.6	55130	54700–55600
5.7	488.7	8120	7950–8290	9.7	492.7	26930	26600–27200	13.7	496.7	55980	55600–56400
5.8	488.8	8470	8290–8640	9.8	492.8	27530	27200–27800	13.8	496.8	56840	56400–57300
5.9	488.9	8820	8640–9000	9.9	492.9	28140	27800–28400	13.9	496.9	57700	57300–58100
6.0	489.0	9180	9000–9360	10.0	493.0	28750	28400–29100	14.0	497.0	58570	58100–59000

(continued)

DEPTH (ft)	LEVEL (ft above msl)	FLOW (cfs)	FLOW RANGE (cfs)	DEPTH (ft)	LEVEL (ft above msl)	FLOW (cfs)	FLOW RANGE (cfs)	DEPTH (ft)	LEVEL (ft above msl)	FLOW (cfs)	FLOW RANGE (cfs)
14.1	497.1	59450	59000–59900	18.1	501.1	99760	99200–100000	22.1	505.1	150300	150000–151000
14.2	497.2	60330	59900–60800	18.2	501.2	100900	100000–101000	22.2	505.2	151700	151000–152000
14.3	497.3	61220	60800–61700	18.3	501.3	102000	101000–103000	22.3	505.3	153100	152000–154000
14.4	497.4	62110	61700–62600	18.4	501.4	103200	103000–104000	22.4	505.4	154500	154000–155000
14.5	497.5	63020	62600–63500	18.5	501.5	104400	104000–105000	22.5	505.5	155900	155000–157000
14.6	497.6	63920	63500–64400	18.6	501.6	105500	105000–106000	22.6	505.6	157300	157000–158000
14.7	497.7	64840	64400–65300	18.7	501.7	106700	106000–107000	22.7	505.7	158800	158000–159000
14.8	497.8	65760	65300–66200	18.8	501.8	107900	107000–108000	22.8	505.8	160200	159000–161000
14.9	497.9	66690	66200–67200	18.9	501.9	109000	108000–110000	22.9	505.9	161600	161000–162000
15.0	498.0	67620	67200–68100	19.0	502.0	110200	110000–111000	23.0	506.0	163100	162000–164000
15.1	498.1	68560	68100–69000	19.1	502.1	111400	111000–112000	23.1	506.1	164500	164000–165000
15.2	498.2	69510	69000–70000	19.2	502.2	112600	112000–113000	23.2	506.2	166000	165000–167000
15.3	498.3	70460	70000–70900	19.3	502.3	113800	113000–114000	23.3	506.3	167500	167000–168000
15.4	498.4	71420	70900–71900	19.4	502.4	115100	114000–116000	23.4	506.4	168900	168000–170000
15.5	498.5	72390	71900–72900	19.5	502.5	116300	116000–117000	23.5	506.5	170400	170000–171000
15.6	498.6	73360	72900–73900	19.6	502.6	117500	117000–118000	23.6	506.6	171900	171000–173000
15.7	498.7	74340	73900–74800	19.7	502.7	118700	118000–119000	23.7	506.7	173400	173000–174000
15.8	498.8	75330	74800–75800	19.8	502.8	120000	119000–121000	23.8	506.8	174900	174000–176000
15.9	498.9	76320	75800–76800	19.9	502.9	121200	121000–122000	23.9	506.9	176400	176000–177000
16.0	499.0	77320	76800–77800	20.0	503.0	122500	122000–123000	24.0	507.0	177900	177000–179000
16.1	499.1	78320	77800–78800	20.1	503.1	123800	123000–124000	24.1	507.1	179400	179000–180000
16.2	499.2	79330	78800–79800	20.2	503.2	125000	124000–126000	24.2	507.2	180900	180000–182000
16.3	499.3	80350	79800–80900	20.3	503.3	126300	126000–127000	24.3	507.3	182500	182000–183000
16.4	499.4	81370	80900–81900	20.4	503.4	127600	127000–128000	24.4	507.4	184000	183000–185000
16.5	499.5	82400	81900–82900	20.5	503.5	128900	128000–130000	24.5	507.5	185600	185000–186000
16.6	499.6	83440	82900–84000	20.6	503.6	130200	130000–131000	24.6	507.6	187100	186000–188000
16.7	499.7	84480	84000–85000	20.7	503.7	131400	131000–132000	24.7	507.7	188700	188000–189000
16.8	499.8	85530	85000–86100	20.8	503.8	132800	132000–133000	24.8	507.8	190200	189000–191000
16.9	499.9	86590	86100–87100	20.9	503.9	134100	133000–135000	24.9	507.9	191800	191000–193000
17.0	500.0	87650	87100–88200	21.0	504.0	135400	135000–136000	25.0	508.0	193400	193000–194000
17.1	500.1	88720	88200–89300	21.1	504.1	136700	136000–137000	25.1	508.1	194900	194000–196000
17.2	500.2	89790	89300–90300	21.2	504.2	138000	137000–139000	25.2	508.2	196500	196000–197000
17.3	500.3	90880	90300–91400	21.3	504.3	139400	139000–140000	25.3	508.3	198100	197000–199000
17.4	500.4	91960	91400–92500	21.4	504.4	140700	140000–141000	25.4	508.4	199700	199000–201000
17.5	500.5	93060	92500–93600	21.5	504.5	142100	141000–143000	25.5	508.5	201300	201000–202000
17.6	500.6	94160	93600–94700	21.6	504.6	143400	143000–144000	25.6	508.6	202900	202000–204000
17.7	500.7	95260	94700–95800	21.7	504.7	144800	144000–145000	25.7	508.7	204600	204000–205000
17.8	500.8	96380	95800–96900	21.8	504.8	146200	145000–147000	25.8	508.8	206200	205000–207000
17.9	500.9	97500	96900–98100	21.9	504.9	147500	147000–148000	25.9	508.9	207800	207000–209000
18.0	501.0	98620	98100–99200	22.0	505.0	148900	148000–150000	26.0	509.0	209500	209000–210000

DEPTH = reading from gage at the Susquehanna SES Environmental Laboratory

LEVEL = DEPTH + 483.0

when LEVEL $\geq$ 486.0, FLOW = 319.96989(LEVEL)^2 - 309316.24395(LEVEL) + 74753300

when LEVEL < 486.0, logFLOW = - 0.05251(LEVEL)^2 + 51.478501(LEVEL) - 12612.85672

FLOW RANGE denotes expected variation at the observed DEPTH.