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September 25, 2009

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

**BELL BEND NUCLEAR POWER PLANT
RESPONSE TO ENVIRONMENTAL
REQUESTS FOR ADDITIONAL
INFORMATION, FIFTH SUBMITTAL
BNP-2009-282 Docket No. 52-039**

References: 1) Letter from U.S. NRC Document Control Desk to R.R. Sgarro (PPL), "Requests for Additional Information Related to the Environmental Review for the Combined License Application for Bell Bend Nuclear Power Plant," dated July 10, 2009

The purpose of this letter is to respond to several Environmental Report (ER) requests for additional information (RAIs) identified in the referenced NRC correspondence to PPL Bell Bend, LLC. These RAIs address environmental issues, as discussed in Part 3 of the Bell Bend Nuclear Power Plant Combined License Application (COLA).

Enclosure 1 provides the current ER RAI response status and the planned submittal dates for the remaining responses. The planned submittal date for some of the RAIs has been changed as compared to the schedule provided in PPL letter BNP-2009-266, dated September 17, 2009. These RAIs are identified with a footnote in Enclosure 1.

PPL plans to transmit a series of responses to the RAIs on or before the planned submittal dates provided in Enclosure 1. The planned submittal schedule is subject to change as PPL collects/develops the information required for the responses. PPL will keep the NRC staff informed of schedule changes during our weekly status updates in addition to updates in our subsequent submittals. Enclosure 2 provides responses to 12 RAIs. Two RAIs include revised COLA content. A Licensing Basis Document Change Request has been initiated to incorporate these changes in a future revision of the COLA.

The commitment contained in this submittal is the future revision of the COLA as indicated in Enclosure 2.

Enclosure 3 contains a calculation that supports the response to RAI H 5.2-1.

D079
NRO

If you have any questions, please contact the undersigned at 570-802-8102.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on September 25, 2009

Respectfully,

Rocco R. Sgarro

RRS/kw

Enclosures: 1) Response Status for Environmental Requests for Additional Information, Bell Bend Nuclear Power Plant, Luzerne County Pennsylvania

2) Responses to Environmental Requests for Additional Information, Bell Bend Nuclear Power Plant, Luzerne County Pennsylvania

3) RAI H 5.2-1 Calculation, Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2), September 18, 2009, Bell Bend Nuclear Power Plant, Luzerne County Pennsylvania,

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Enclosure 1

Response Status for Environmental Requests for Additional Information
Bell Bend Nuclear Power Plant
Luzerne County Pennsylvania

NRC Response Status for Environmental Requests for Additional Information (RAIs)		
RAI	**Review Plan Section**	**Planned Submittal Schedule**
ACC 7.1-1	ESRP 7.1.10	Submitted August 10, 2009
ACC 7.1-2	ESRP 7.1	Submitted August 5, 2009
ACC 7.2-1	ESRP 7.2	Submitted August 10, 2009
ACC 7.2-2	ESRP 7.2	Submitted August 10, 2009
ACC 7.2-3	ESRP 7.2	Submitted August 10, 2009
ACC 7.2-4	ESRP 7.2	Submitted August 10, 2009
ACC 7.2-5, (revised response)	ESRP 7.2	October 16, 2009[1,2]
ACC 7.2-6	ESRP 7.2	Submitted August 10, 2009
ACC 7.3-1	ESRP 7.3	Submitted September 17, 2009
ACC 7.3-2	ESRP 7.3	Submitted August 10, 2009
ACC 7.3-3	N/A	Submitted August 10, 2009
ACC 7.3-4	N/A	Included in Enclosure 2
ACC 7.3-5	N/A	Submitted August 10, 2009
MET 2.7-1	ESRP 2.7	November 30, 2009[1,2]
MET 2.7-2	ESRP 2.7	October 16, 2009[1,2]
MET 2.7-3	ESRP 2.7	Submitted September 11, 2009
MET 2.7-4	ESRP 2.7	Submitted September 17, 2009
MET 5.3-1	ESRP 2.7, ESRP 5.3.3.1	October 16, 2009[1,2]
MET 5.3-2	ESRP 2.7, ESRP 5.3.3.1	Submitted August 10, 2009
MET 5.3-3	ESRP 5.3.3.1	Submitted August 10, 2009
MET 5.3-4	ESRP 5.3.3.1	Submitted September 11, 2009
MET 5.3-5	ESRP 5.3.3.1	Submitted August 10, 2009
MET 6.4-1	ESRP 2.7, ESRP 6.4	Submitted September 17, 2009
MET 6.4-2	ESRP 6.4	Submitted September 17, 2009
ALT 9.3-1	ESRP 9.3	November 18, 2009[1,2]
ALT 9.3-2	ESRP 9.3	October 16, 2009[1,2]
ALT 9.3-3	ESRP 9.3	Submitted September 11, 2009
ALT 9.3-4	ESRP 9.3	Included in Enclosure 2
ALT 9.3-5	ESRP 9.3	November 18, 2009[1,2]
AE 2.3-1	ESRP 2.3.1	October 16, 2009[1,2]
AE 2.3-2	ESRP 2.3.1	Submitted August 5, 2009
AE 2.3-3	ESRP 2.3.1	Included in Enclosure 2
AE 2.4-1	ESRP 2.4.2	Submitted August 5, 2009
AE 2.4-2	ESRP 2.4.2	Submitted August 5, 2009
AE 2.4-3	ESRP 2.4.2	Submitted August 5, 2009
AE 2.4-4	ESRP 2.4.2	Submitted August 5, 2009
AE 2.4-5	ESRP 2.4.2	Submitted August 5, 2009
AE 3.4-1	ESRP 3.4.2	Submitted August 10, 2009
AE 3.4-2	ESRP 3.4.2	October 16, 2009[1,2]
AE 3.4-3	ESRP 3.4.2	Submitted August 10, 2009
AE 3.4-4	ESRP 3.4.2	Submitted August 10, 2009
AE 4.3-1	ESRP 4.3.2	Submitted August 5, 2009
AE 4.3-2	ESRP 4.3.2	January 15, 2010[1,2]
AE 4.3-3	ESRP 4.3.2	October 16, 2009[1,2]
AE 4.3-4	ESRP 4.3.2	October 16, 2009[1,2]
AE 5.3-1	ESRP 5.3.1.2	Submitted August 10, 2009
AE 5.3-2	ESRP 5.3.1.2	Submitted August 5, 2009
AE 9.3-1	ESRP 9.3	November 18, 2009[1,2]
AE 9.3-2	ESRP 9.3	Submitted September 17, 2009
AE 9.3-3	ESRP 9.3	Submitted September 17, 2009
AE 9.3-4	ESRP 9.3	November 18, 2009[1,2]
CR 2.5-1	ESRP 4.1.3, ESRP 5.1.3	Submitted August 10, 2009

NRC Response Status for Environmental RAIs (continued)		
RAI	Review Plan Section	Planned Submittal Schedule
CR 2.5-2	ESRP 4.1.3	Submitted August 10, 2009
CR 2.5-3	ESRP 4.1.3, ESRP 5.1.3	Submitted August 10, 2009
CR 2.5-4	ESRP 4.1.3, ESRP 5.1.3	Submitted August 10, 2009
CR 2.5-5	ESRP 2.5.2, ESRP 2.5.3	Submitted August 10, 2009
CR 2.5-6	ESRP 2.5.2, ESRP 2.5.3	November 18, 2009[1,2]
CR 2.5-7	ESRP 4.1.3, ESRP 5.1.3	November 18, 2009[1,2]
CR 2.5-8	ESRP 4.1.3, ESRP 5.1.3	November 18, 2009[1,2]
STO 1-1	N/A	October 16, 2009[1,2]
STO 2.1-1	ESRP 2.2, 2.4, 2.5, 4.3	November 18, 2009[1,2]
STO 2.1-2	ESRP 2.1	Submitted August 10, 2009
STO 2.2-1	ESRP 2.2	Submitted September 17, 2009
STO 2.3-1	ESRP 2.3	Included in Enclosure 2
GEO 2.6-1	ESRP 2.6	Submitted September 11, 2009
H 2.3-1	ESRP 2.3-2	Submitted September 17, 2009
H 2.3-2	ESRP 2.3-2	Submitted September 17, 2009
H 3.4-1	ESRP 3.4.1	Included in Enclosure 2
H 3.6-1	ESRP 3.6.1	Submitted September 17, 2009
H 3.6-2	ESRP 3.6.1	Submitted August 5, 2009
H 4.2-1	ESRP 4.2.1	October 16, 2009[1,2]
H 5.2-1	ESRP 5.2.2	Included in Enclosure 2
H 5.3-1	ESRP 5.3.2.1	November 18, 2009[1,2]
H 6.3-1	ESRP 6.3	October 16, 2009[1,2]
H 9.3-1	ESRP 9.3	November 18, 2009[1,2]
H 9.4-1	ESRP 9.4.2	Submitted August 10, 2009
H 9.4-2	ESRP 9.4.2	Submitted August 10, 2009
H 9.4-3	ESRP 9.4.2	Submitted September 11, 2009
LU 2.2-1	ESRP 2.2.1	Submitted August 5, 2009
LU 3.7-1	ESRP 4.1	January 15, 2010[1]
LU 4.1-1	ESRP 4.1	January 15, 2010[1]
LU 5.1-1	ESRP 4.1	January 15, 2010[1]
LU 5.1-2	ESRP 4.1	January 15, 2010[1]
NRHH 10.5-1	N/A	Submitted August 10, 2009
RHH 4.5-1	ESRP 4.5, ESRP 5.4-2	Submitted August 10, 2009
RHH 4.5-2	ESRP 4.5	October 16, 2009[1,2]
RHH 4.5-3	ESRP 4.5	Included in Enclosure 2
RHH 5.4-1	ESRP 5.4.2	Submitted September 11, 2009
SE 2.5-1	ESRP 2.5.1	Submitted August 5, 2009
SE 2.5-2	ESRP 2.5.1	October 16, 2009[1,2]
SE 2.5-3	ESRP 2.5.2	October 16, 2009[1,2]
SE 2.5-4	ESRP 2.5.2	October 16, 2009[1,2]
SE 2.5-5	ESRP 2.5.2	Submitted August 10, 2009
SE 2.5-6	ESRP 2.5.2	Submitted August 5, 2009
SE 2.5-7	ESRP 2.5.2	October 16, 2009[1,2]
SE 2.5-8	ESRP 2.5.2	October 16, 2009[1,2]
SE 2.5-9	ESRP 2.5.2	Submitted September 11, 2009
SE 2.5-10	ESRP 2.5.4	Submitted September 17, 2009
SE 2.5-11	ESRP 2.5.4	Submitted August 10, 2009
SE 2.5-12	ESRP 2.5.4	Submitted August 10, 2009
SE 2.5-13	ESRP 2.5.4	Submitted September 17, 2009
SE 4.4-1	ESRP 4.4.1	Submitted August 10, 2009
SE 4.4-2	ESRP 4.4.1	Submitted August 10, 2009
SE 4.4-3	ESRP 4.4.2	Included in Enclosure 2
SE 4.4-4	ESRP 4.4.2	November 18, 2009[1,2]
SE 4.4-5	ESRP 4.4.2	Submitted August 5, 2009

NRC Response Status for Environmental RAIs (continued)		
RAI	**Review Plan Section**	**Planned Submittal Schedule**
SE 4.4-6	ESRP 4.4.2	Submitted August 10, 2009
SE 4.4-7	ESRP 4.4.2	Submitted September 17, 2009
SE 4.4-8	ESRP 4.4.2	Submitted September 17, 2009
SE 4.4-9	ESRP 4.4.2	November 18, 2009[1,2]
SE 4.4-10	ESRP 4.4.2	Submitted September 17, 2009
SE 4.4-11	ESRP 4.4.2	October 16, 2009[1,2]
SE 4.4-12	ESRP 4.4.2	Included in Enclosure 2
SE 4.4-13	ESRP 4.4.2	October 16, 2009[1,2]
SE 4.4-14	ESRP 4.4.3	Submitted September 17, 2009
SE 5.8-1	ESRP 5.8.2	Submitted September 17, 2009
SE 5.8-2	ESRP 5.8.2	Submitted August 5, 2009
CB 10.4-1	ESRP 10.4.2	November 18, 2009[1,2]
TE 2.4-1	ESRP 2.2.1	Submitted August 10, 2009
TE 2.4-2	ESRP 2.2.1	Submitted August 5, 2009
TE 2.4-3	ESRP 2.4.1	Submitted September 11, 2009
TE 2.4-4	ESRP 2.4.1	Submitted August 10, 2009
TE 2.4-5, (revised response)	ESRP 2.4.1	Submitted September 11, 2009
TE 2.4-6	ESRP 2.4.1	January 15, 2010[1,2]
TE 2.4-7	ESRP 2.4.1	January 15, 2010[1]
TE 2.4-8	ESRP 2.4.1	January 15, 2010[1,2]
TE 4.3-1	ESRP 4.3.1	January 15, 2010[1]
TE 4.3-2	ESRP 4.3.1	January 15, 2010[1]
TE 4.3-3	ESRP 4.3.1	Submitted September 11, 2009
TE 4.3-4	ESRP 4.3.1	January 15, 2010[1]
TE 4.3-5	ESRP 4.3.1	Submitted August 10, 2009
TE 4.3-6	ESRP 4.3.1	Submitted August 10, 2009
TE 4.3-7	ESRP 4.3.1, ESRP 9.3	January 15, 2010[1]
TE 4.3-8	ESRP 4.3.1	October 16, 2009[1]
TE 4.3-9	ESRP 4.3.1	Included in Enclosure 2
TE 4.3-10	ESRP 4.3.1	January 15, 2010[1]
TR 4.7-1	ESRP 4.7	Included in Enclosure 2
TR 4.7-2	ESRP 4.7	Submitted August 10, 2009

USACE Response Status for Environmental RAIs	
RAI	**Planned Submittal Schedule**
USACE-1	November 18, 2009[1,2]
USACE-1a	November 18, 2009[1,2]
USACE-1b	November 18, 2009[1,2]
USACE-2	November 18, 2009[1,2]
USACE-2a	November 18, 2009[1,2]
USACE-2b	November 18, 2009[1,2]
USACE-2c	November 18, 2009[1,2]
USACE-2d	November 18, 2009[1,2]
USACE-2e	November 18, 2009[1,2]
USACE-2f	November 18, 2009[1,2]
USACE-2g	Included in Enclosure 2
USACE-2h	November 18, 2009[1,2]
USACE-3	November 18, 2009[1,2]

[1]The responses to these RAIs were requested to be provided within 30 calendar days. Based on vendor review and input, the time required to complete the necessary work will exceed this timeframe and PPL requests additional time, as indicated above.

[2]The response date to these RAIs has been revised since the September 17, 2009, submittal.

Enclosure 2

Responses to Environmental Requests for Additional Information
Bell Bend Nuclear Power Plant
Luzerne County Pennsylvania

ACC 7.3-4

Summary: *Provide an evaluation of each of the 51 SAMDA candidates listed in Table 6.2 of the EPR design certification ER.*

Full Text: AREVA lists 51 SAMDA candidates that were deferred because they were not required for design certification. Most, but not all, of these candidates pertain to procedures and training. The ER implicitly assumes that all 51 of the deferred candidates are related to procedures and training by not addressing any of the candidates. However, there are at least six candidates in the design certification list of 51 that are site specific and do not refer to procedures and training. Because of the proposed facility's proximity to the SSES, some SAMDA candidates that refer to multiunit sites may be feasible; therefore, please address all multiunit SAMAs from the design certification list as well. To be sure that no candidates is overlooked, the BBNPP ER should address each candidate in the list.

Response: The Severe Accident Mitigation Design Alternatives (SAMDA) candidates categorized as "Not Required for Design Certification" in Table 6-2 of the "AREVA NP Environmental Report Standard Design Certification" (ANP-10290 Rev. 1) were re-evaluated for Bell Bend. These SAMDA candidates were re-evaluated using the screening methodology in Section 7.3.1 of BBNPP Environmental Report. An additional screening category called "Not a Design Alternative" was used to capture any SAMDA candidate not related to the plant design. This category would include SAMDA candidates related to procedure modifications, training, and surveillance. If a SAMDA candidate is related to any of these enhancements, it is not retained for this analysis.

Table 7.3-4-1 includes the screening category and the basis for the category selection for the re-evaluated SAMDA candidates for Bell Bend.

Table 7.3-4-1: Screening of "Not Required for Design Certification" SAMDA Candidates for BBNPP

SAMDA ID	Potential Enhancement	Screening Criterion	Basis for Screening/Modification Evaluation
Enhancements Related to AC and DC Power			
AC/DC-08	Increase training on response to loss of two 120V AC buses which causes inadvertent actuation signals	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
AC/DC-10	Revise procedure to allow bypass of diesel generator trips.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

AC/DC-12	Create AC power cross-tie capability with other unit (multi-unit site)	Not Applicable	The unit at Bell Bend and the units at Susquehanna Steam Electric Station (SSES) are geographically and physically separated. Also, the units are owned and operated by different entities. Therefore, this SAMDA is considered not applicable for the U.S. EPR at Bell Bend.
AC/DC-17	Create a cross-tie for diesel fuel oil (multi-unit site).	Not Applicable	The unit at Bell Bend and the units at Susquehanna Steam Electric Station (SSES) are geographically and physically separated. Also, the units are owned and operated by different entities. Therefore, this SAMDA is considered not applicable for the U.S. EPR at Bell Bend.
AC/DC-18	Develop procedures for replenishing diesel fuel oil.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
AC/DC-21	Develop procedures to repair or replace failed 4KV breakers.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
AC/DC-22	In training, emphasize steps in recovery of off-site power after an Station blackout (SBO).	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be design alternative for the U.S. EPR.
AC/DC-23	Develop a severe weather conditions procedure.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

Enhancements Related to Anticipated Transient Without Scram (ATWS)			
AT-05	Revise procedure to bypass Main Steam Isolation Valve isolation in turbine trip Anticipated Transient Without Scram (ATWS) scenarios.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
AT-06	Revise procedure to allow override of low pressure core injection during an ATWS event.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
Enhancements Related to Containment Bypass			
CB-03	Increase leak testing of valves in Interfacing System Loss of Coolant Accident (ISLOCA) paths.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CB-07	Revise Emergency Operating Procedures (EOP) to improve ISLOCA identification.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CB-08	Improve operator training on ISLOCA coping.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CB-09	Institute a maintenance practice to perform a 100% inspection of steam generator tubes during each refueling outage.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CB-13	Proceduralize use of pressurizer vent valves during steam generator tube rupture sequences.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

CB-17	Revise emergency operating procedures to direct isolation of a faulted steam generator.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CB-18	Direct steam generator flooding after a steam generator tube rupture, prior to core damage.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
Enhancements Related to Core Cooling Systems			
CC-03	Revise procedure to allow operators to inhibit automatic vessel depressurization in non-ATWS scenarios.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CC-09	Provide hardware and procedure to refill the reactor water storage tank once it reaches a specified low level	Already Implemented / Not a Design Alternative	Refill or make-up water sources for the In-containment Refueling Water Storage Tank (IRWST) include the Reactor Boron Water Makeup System (RBWMS), Fuel Pool Purification System (FPPS) and the Demineralized Water Distribution System (DWDS). The procedures part of this SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CC-12	Emphasize timely recirculation alignment in operator training.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CC-18	Make procedure changes for reactor coolant system depressurization.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

Enhancements Related to Containment Phenomena			
CP-14	Institute simulator training for severe accident scenarios.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CP-15	Improve leak detection procedures.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CP-16	Delay containment spray actuation after a large LOCA.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
Enhancements Related to Cooling Water			
CW-03	Enhance procedural guidance for use of cross-tied component cooling or service water pumps.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CW-07	Enhance loss of component cooling water (or loss of service water) procedures to facilitate stopping the reactor coolant pumps.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CW-08	Enhance loss of component cooling water procedure to underscore the desirability of cooling down the reactor coolant system prior to seal LOCA.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

CW-09	Additional training on loss of component cooling water.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CW-11	On loss of essential raw cooling water, proceduralize shedding component cooling water loads to extend the component cooling water heat-up time.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CW-19	Change procedures to isolate reactor coolant pump seal return flow on loss of component cooling water, and provide (or enhance) guidance on loss of injection during seal LOCA.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
CW-20	Implement procedures to stagger high pressure safety injection pump use after a loss of service water.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
U.S. EPR Specific Enhancements			
EPR-02	Training for operator actions during small-break Loss of Coolant Accident (SLOCA) scenarios.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
EPR-03	Operator training to initiate Residual Heat Removal (RHR) system.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

EPR-04	Training for operator actions during Steam Generator Tube Rupture (SGTR) scenarios.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
EPR-06	Provide operator training on manually actuating the Extra Borating System (EBS).	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
EPR-07	Provide operator training to cross tie Division 1 to Division 2 or Division 4 to Division 3 during both a station black out and non-SBO event.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
Enhancements Related to Internal Flooding			
FL-01	Improve inspection of rubber expansion joints on main condenser.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
Enhancements to Reduce Fire Risk			
FR-01	Replace mercury switches in fire protection system.	Not Applicable	When the U.S. EPR plant is constructed at Bell Bend the equipment being installed will be state of the art for the time. Therefore, replacing the mercury switches is considered not applicable to the U.S. EPR.
FR-04	Enhance fire brigade awareness.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

Enhancements Related to Feedwater and Condensate			
FW-09	Proceduralize local manual operation of auxiliary feedwater system when control power path is lost.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
FW-13	Provide a passive, secondary- side heat-rejection loop consisting of a condenser and heat sink.	Excessive Implementation Cost	The cost of implementing a similar SAMDA at Shearon Harris was estimated by Carolina Power and Light Company to require more than $1,700,000 in 2007. Therefore, this SAMDA is not considered cost beneficial to implement in the U.S. EPR based on this evaluation.
FW-16	Perform surveillances on manual valves used for backup auxiliary feedwater pump suction	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
Enhancements Related to Heating, Ventilation, and Air Conditioning			
HV-03	Stage backup fans in switchgear rooms..	Already Implemented	The U.S. EPR design has four separate safety divisions each with a switchgear room (U.S. EPR FSAR Section 3.8.4.1) and corresponding ventilation system (U.S. EPR FSAR Section 9.4.6.2.1). In an event of loss of switchgear ventilation in one division, the corresponding equipment that is cooled by the ventilation will become unavailable. Since the U.S. EPR has four divisions, each one of the remaining three divisions is capable of performing the intended functions of the off-line division. Therefore, the intent of this SAMDA is considered to have already been implemented for the U.S. EPR.
Enhancements Related to Instrument Air and Nitrogen Supply			
IA-02	Modify procedure to provide ability to align diesel power to more air compressors.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

IA-03	Replace service and instrument air compressors with more reliable compressors which have self-contained air cooling by shaft driven fans	Not Applicable	The compressed air system is a non-safety related system for the U.S. EPR (with the exception of the containment isolation valves). The system, with respect to the safe shutdown of the plant, is not required to operate for the duration of or following an accident. Malfunction of any component of this system does not affect the safe operation of the plant or any safety related system. Therefore, there are no failure criteria or reliability issues applicable to this system for the U.S. EPR.
Other Enhancements			
OT-02	Enhance procedures to mitigate large break LOCA.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
OT-03	Install computer aided instrumentation system to assist the operator in assessing post-accident plant status.	Already Implemented	The U.S. EPR design has a Post Accident Monitoring (PAM) system which permits the operator to assess post-accident plant conditions, safety system performance, and determine appropriate actions to take to respond to abnormal events (U.S. EPR FSAR Chapter 7.5.1.2). Therefore, the intent of this SAMDA is considered to have already been implemented for the U.S. EPR.
OT-04	Improve maintenance procedures.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.
OT-05	Increase training and operating experience feedback to improve operator response.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

OT-06	Develop procedures for transportation and nearby facility accidents.	Not a Design Alternative	This SAMDA candidate does not affect the U.S. EPR plant design. Therefore, this SAMDA is considered not to be a design alternative for the U.S. EPR.

Below is an updated summary of results of the SAMDA analysis performed for BBNPP based on the revised analysis above:

- Twenty-five SAMDA candidates were not applicable to the U.S. EPR design.
- Sixty-nine SAMDA candidates were already implemented into the U.S. EPR design either as suggested in the SAMDA candidate or an equivalent replacement that fulfilled the intent of the SAMDA.
- Four SAMDA candidates were combined with another SAMDA candidate because they had the same intent.
- Forty-three SAMDA candidates were categorized as not a design alternative because they were related to procedure modifications, training, or surveillance.
- One of the SAMDA candidates was categorized as very low benefit.
- Twenty-five SAMDA candidates were categorized as excessive implementation cost.
- None of the SAMDA candidates were categorized as consider for further evaluation.

The overall conclusion of the Bell Bend SAMDA analysis is that no additional plant modifications are cost beneficial to implement due to the robust design of the U.S. EPR with respect to prevention and mitigation of severe accidents.

Reference cited in response: ANP-10290 Rev. 1. AREVA NP Environmental Report Standard Design Certification, ANP-10290, Revision 1, AREVA NP, September 2009.

COLA Impact:
BBNPP COLA ER Section 7.3.1, and 7.3.3 will be revised as follows in a future revision of the COLA:

7.3.1 SAMDA ANALYSIS METHODOLOGY

The methodology used to develop a comprehensive list of U.S. EPR SAMDA candidates, define the screening criteria used to categorize the SAMDA candidates, and the cost-benefit evaluation is summarized in this section based on the U.S. EPR DC ER (AREVA, ~~2007~~2009) for the U.S. EPR.

The comprehensive list of SAMDA candidates was developed for the U.S. EPR by reviewing industry documents for generic PWR enhancements and considering plant-specific enhancements. The SAMDA candidates were defined as enhancements to the U.S. EPR plant that have the potential to prevent core damage and significant releases from the containment. The primary industry document supporting the development of U.S. EPR generic PWR SAMDA candidates was NEI 05-01 (NEI, 2005).

In addition to the generic SAMDA candidates, the results of the Level 1 and Level 2 PRA are reviewed to identify plant-specific modifications for inclusion in the comprehensive list of SAMDA candidates.

The U.S. EPR top 100 core damage frequency (CDF) cutsets were evaluated to identify those modifications that would reduce the likelihood of occurrence of the significant core damage sequences. As stated in the U.S. EPR FSAR Section 19.1.4.1.2.3 (Significant Cutsets and Sequences), ninety-five percent of the total CDF is represented by over 12,000 cutsets for the U.S. EPR; however, the top 100 cutsets include all cutsets contributing >1 percent to the total CDF. For the U.S. EPR application, this equates to approximately 50 percent of the total CDF. In fact the selection of the top 100 cutsets conservatively includes cutsets of low importance. For example, the percentage of the individual contribution to the total CDF for the 101st cutset was 0.10 percent.

The U.S. EPR top 100 large release frequency (LRF) cutsets were evaluated to identify those modifications that would reduce the likelihood of occurrence of the significant containment challenges. This population of cutsets specifically excluded the contribution to LRF of the core damage sequences due to Main Steam Line Break (MSLB) inside containment with main feedwater unisolated, as this sequence of events was determined not to lead to core damage or LERF after submittal of the U.S. EPR FSAR. This exclusion ensures that the overly conservative treatment of an event does not artificially reduce the importance of other containment failure mechanisms. The top 100 LRF cutsets include all cutsets contributing greater than 1 percent to the total LRF. For the U.S. EPR application this equates to approximately 50 percent of the total LRF, and includes many low importance cutsets that contribute only 0.10 percent to the total LRF.

Consistent with current regulatory guidance and industry practice, all risk significant design alternatives for the U.S. EPR have been addressed by detailed evaluations of the top 100 CDF and LRF cutsets to identify plant-specific modifications for inclusion in the comprehensive list of U.S. EPR SAMDA candidates. Through the evaluation of the top 100 Level 1 PRA cutsets, numerous U.S. EPR specific operator actions and hardware-based SAMDA candidates were developed. When evaluating the top 100 LRF cutsets no additional SAMDA candidates were identified. The U.S. EPR DC ER (AREVA, 2007) provides a detailed list of the SAMDA candidates for the U.S. EPR. The SAMDA candidates identified in the U.S. EPR DC ER are applicable to BBNPP.

The SAMDA candidates developed for the U.S. EPR design were qualitatively screened using seven categories. The intent of the screening is to identify the candidates for further risk-benefit calculation. For each SAMDA candidate, a screening criteria and basis for screening was identified to justify the implementation or exclusion of the SAMDA candidate in the U.S. EPR. The seven categories used during the screening process included:

- Not applicable. The SAMDA candidates were identified to determine which are definitely not applicable to the U.S. EPR. Potential enhancements that are not considered applicable to the U.S. EPR are those developed for systems specifically associated with boiling water reactors (BWR) or with specific PWR equipment that is not in the U.S. EPR design.

- Already implemented. The SAMDA candidates were reviewed to ensure that the U.S. EPR design does not already include features recommended by a particular SAMDA candidate. Also, the intent of a particular SAMDA candidate may have been fulfilled by another design feature or modification. In these cases the SAMDA candidates are already implemented in the U.S. EPR plant design. If a SAMDA candidate has already been implemented at the plant, it is not retained.

- Combined. If one SAMDA candidate is similar to another SAMDA candidate, and can be combined with that candidate to develop a more comprehensive or plant-specific SAMDA candidate, only the combined SAMDA candidate is retained for screening.

- Excessive implementation cost. If a SAMDA candidate requires extensive changes that will obviously exceed the maximum benefit even without an implementation cost estimate and therefore incurs an excessive implementation cost, it is not retained.

- Very low benefit. If a SAMDA candidate is related to a non-risk significant system for which change in reliability is known to have negligible impact on the risk profile, it is deemed to have a very low benefit and is not retained.

- Not required for design certification. Evaluation of any potential procedural or surveillance action SAMDA candidates are not appropriate until the plant design is finalized and the plant procedures are being developed. Therefore, if a SAMDA candidate is related to any of these enhancements, it is not retained for this analysis.

- Considered for further evaluation. If a particular SAMDA candidate was not categorized by any of the preceding categories, then the SAMDA candidate is considered for further evaluation and subject to a cost-benefit analysis.

The screening categories were chosen based on guidance from NEI 05-01. The U.S. EPR DC ER contains a detailed description of each of the categories. The screening categories are applicable to BBNPP.

The SAMDA candidates categorized as "Not required for design certification" in the AREVA NP Environmental Report Standard Design Certification were re-evaluated for BBNPP. These SAMDA candidates were re-evaluated using the screening methodology in AREVA NP Environmental Report Standard Design Certification. An additional screening category called "Not a design alternative" was used to capture any SAMDA candidate not related to plant design. This category included SAMDA candidates related to procedure modifications, training, or surveillance. If a SAMDA candidate is related to any of these enhancements, it is not retained for this analysis.

After the screening process was completed, the SAMDA candidates that were placed in the Considered for Further Evaluation category would require a cost-benefit evaluation. The cost-benefit evaluation of each SAMDA candidate would determine the cost of implementing the specific SAMDA candidate with the maximum averted cost risk from the implementation of the specific SAMDA candidate. The maximum averted cost risk, typically referred to as the maximum benefit, equates to the cost obtained by the elimination of all severe accident risk.

7.3.3 RESULTS AND SUMMARY

A total of 167 SAMDA candidates developed from industry and U.S. EPR documents were evaluated in the U.S. EPR DC ER completed by AREVA NP. The basis for screening is provided in detail for each SAMDA candidate in the U.S. EPR DC ER. Below is a summary of the results of the SAMDA analysis performed for the U.S. EPR and is applicable to BBNPP.

- Twenty-~~one~~ five SAMDA candidates were not applicable to the U.S. EPR design.
- Sixty-~~six~~ nine SAMDA candidates were already implemented into the U.S. EPR design either as suggested in the SAMDA or an equivalent replacement that fulfilled the intent of the SAMDA. These SAMDA candidates are summarized in Table 7.3-2.
- Four SAMDA candidates were combined with another SAMDA because they had the same intent.
- Forty-three SAMDA candidates were categorized as not a design alternative because they were related to procedure modifications, training, or surveillance.~~Fifty-one SAMDA candidates were categorized as not required for design certification because they were related to a procedural or surveillance action. Evaluation of any potential administrative SAMDA candidates (i.e., those candidates related to procedures and training) is not appropriate until the plant design is finalized and plant administrative processes, procedures and training program are being developed. However, the plant administrative processes, procedures, and training program will be developed to address appropriate maintenance and use of the U.S. EPR design features which have been credited with the reduction of risk associated with postulated severe accidents. As such, appropriate administrative controls on plant operations will be incorporated into the BBNPP management system as part of the initial administrative processes, procedures and training program development process.~~

- One SAMDA candidate was categorized as very low benefit.
- Twenty-three five SAMDA candidates were categorized as excessive implementation cost.
- None of the SAMDA candidates were categorized as consider for further evaluation.

The low probability of core damage events in the U.S. EPR coupled with reliable severe accident mitigation features provide significant protection to the public and the environment. Specific severe accident mitigation design alternatives from previous industry studies, and from U.S. EPR probabilistic risk assessment (PRA) insights, were measured against broad acceptance criteria in the U.S. EPR DC ER (AREVA, 20072009). Since none of the SAMDA candidates were categorized as considered for further evaluation, a cost-benefit analysis (i.e., risk reduction, value impact ratios) was not required for the U.S. EPR SAMDA analysis. The overall conclusion of the U.S. EPR SAMDA analysis is that no additional plant modifications are cost beneficial to implement due to the robust design of the U.S. EPR with respect to prevention and mitigation of severe accidents. The maximum benefit from the U.S. EPR DC ER was reevaluated for BBNPP. The detailed analysis and conclusions in the U.S. EPR DC ER remain applicable for BBNPP.

7.3.4 REFERENCES

AREVA, 20072009. AREVA NP Environmental Report Standard Design Certification, ANP-10290, Revision 01, AREVA NP, November 2007September 2009.

Table 7.3-2: SAMDA Candidates – Already Implemented

SAMDA ID	Potential Enhancement
AC/DC-01	Provide additional DC battery capacity.
AC/DC-03	Add additional battery charger or portable, diesel-driven battery charger to existing DC system.
AC/DC-04	Improve DC bus load shedding.
AC/DC-05	Provide DC bus crossties
AC/DC-06	Provide additional DC power to the 120/240V vital AC system.
AC/DC-07	Add an automatic feature to transfer the 120V vital AC bus from normal to standby power.
AC/DC-09	Provide an additional diesel generator.
AC/DC-11	Improve 4.16 kV bus cross-tie ability.
AC/DC-14	Install a gas turbine generator.
AC/DC-16	Improve uninterruptible power supplies.
AC/DC-24	Bury off-site power lines.
AT-01	Add an independent boron injection system.
AT-02	Add a system of relief valves to prevent equipment damage from pressure spikes during an ATWS.
AT-07	Install motor generator set trip breakers in control room.
AT-08	Provide capability to remove power from the bus powering the control rods.
CB-01	Install additional pressure or leak monitoring instruments for detection of ISLOCAs.
CB-04	Install self-actuating containment isolation valves.
CB-10	Replace SGs with a new design.
CB-12	Install a redundant spray system to depressurize the primary system during an SGTR.
CB-14	Provide improved instrumentation to detect SGTR, such as Nitrogen-16 monitors.
CB-16	Install a highly reliable (closed loop) SG shell-side heat removal system that relies on natural circulation and stored water sources.
CB-20	Install relief valves in the CCWS.
CC-01	Install an independent active or passive high pressure injection system.
CC-04	Add a diverse low pressure injection system.
CC-05	Provide capability for alternate injection via diesel-driven fire pump.
CC-06	Improve ECCS suction strainers.
CC-07	Add the ability to manually align ECCS recirculation.
CC-10	Provide an in-containment reactor water storage tank.
CC-15	Replace two of the four electric safety injection pumps with diesel-powered

SAMDA ID	Potential Enhancement
	pumps.
CC-17	Create a reactor coolant depressurization system.
CC-21	Modify the containment sump strainers to prevent plugging.
CP-01	Create a reactor cavity flooding system.
CP-03	Use the fire water system as a backup source for the containment spray system.
CP-07	Provide post-accident containment inerting capability.
CP-08	Create a large concrete crucible with heat removal potential to contain molten core debris.
CP-11	Increase depth of the concrete base mat or use an alternate concrete material to ensure melt-through does not occur.
CP-13	Construct a building to be connected to primary/secondary containment and maintained at a vacuum.
CP-17	Install automatic containment spray pump header throttle valves.
CP-20	Install a passive hydrogen control system.
CP-21	Erect a barrier that would provide enhanced protection of the containment walls (shell) from ejected core debris following a core melt scenario at high pressure.
CP-22	Install a secondary containment filtered ventilation.
CW-01	Add redundant DC control power for SW pumps.
CW-02	Replace ECCS pump motors with air-cooled motors.
CW-04	Add a SW pump.
CW-05	Enhance the screen wash system.
CW-06	Cap downstream piping of normally closed component cooling water drain and vent valves.
CW-10	Provide hardware connections to allow another essential raw cooling water system to cool charging pump seals.
CW-15	Use existing hydro test pump for RCP seal injection.
CW-16	Install improved RCP seals.
CW-17	Install an additional component cooling water pump.
EPR-01	Provide an additional SCWS train.
EPR-05	Add redundant pressure sensors to the pressurizer and SG.
FR-03	Install additional transfer and isolation switches.
FR-05	Enhance control of combustibles and ignition.
FW-01	Install a digital feed water upgrade.
FW-02	Create ability for emergency connection of existing or new water sources to feedwater and condensate systems.

SAMDA ID	Potential Enhancement
FW-04	Add a motor-driven feedwater pump.
FW-07	Install a new condensate storage tank (auxiliary feedwater storage tank).
FW-11	Use fire water system as a backup for SG inventory.
FW-15	Replace existing pilot-operated relief valves with larger ones, such that only one is required for successful feed and bleed.
HV-01	Provide a redundant train or means of ventilation to the switch gear rooms.
HV-02	Add a diesel building high temperature alarm or redundant louver and thermostat.
HV-03	Stage backup fans in switchgear rooms.
HV-04	Add a switchgear room high temperature alarm.
HV-05	Create ability to switch EFW room fan power supply to station batteries in an SBO.
SR-01	Increase seismic ruggedness of plant components.
SR-02	Provide additional restraints for CO_2 tanks.
OT-01	Install digital large break LOCA protection system.
OT-03	Install computer aided instrumentation system to assist the operator in assessing post-accident plant status.

ALT 9.3-4

ESRP 9.3

Summary: *Address the effect on the alternative site ranking if the State identifies Walker Branch as a protected trout stream.*

Full Text: The State has clearly indicated that if the stream is designated (June 2009 forecast for determination) as trout waters of the State, then associated wetlands would be considered of "Exceptional Value" and removal of these wetlands may not be allowed by the State for the purpose of construction of BBNPP. Address whether there would be a change in the relative ranking of alternative sites, or the potential for another site to be environmentally preferable or obviously superior resulting from this designation if/when it occurs.

Response: The Commonwealth of Pennsylvania has not designated the Walker Run associated wetlands as "Exceptional Value" at this time. When a decision on the status of Walker Run is finalized, we will promptly inform the NRC.

BBNPP's intention to relocate Walker Run as part of the development plan as stated in the COLA has been reevaluated and a decision has been made not to relocate the stream.

Regarding the impact of the potential "Exceptional Value" classification on the relative ranking of alternative sites, BBNPP has conducted a reevaluation of alternative sites consistent with a revised screening process. The identification of Walker Run as a trout stream and the potential "Exceptional Value" classification has not affected the relative ranking of the BBNPP site. The results of the revised alternative site evaluation are contained in the Bell Bend Nuclear Power Plant Alternate Site Evaluation Rev.0 report, submitted to the NRC in letter BNP-2009-257 on September 9, 2009.

COLA Impact:
Changes to the BBNPP COLA ER are under development in support of the aforementioned Alternative Site Evaluation Report that has been submitted to the NRC. These changes, to COLA ER Sections 9.3 and 10.4, will be forwarded to the NRC under separate cover in support of an upcoming NRC Alternative Sites audit.

AE 2.3-3

ESRP 2.3-1

Summary: *Provide correct water depth (as feet below a standard reference point) at the intake and discharge areas in the Susquehanna River.*

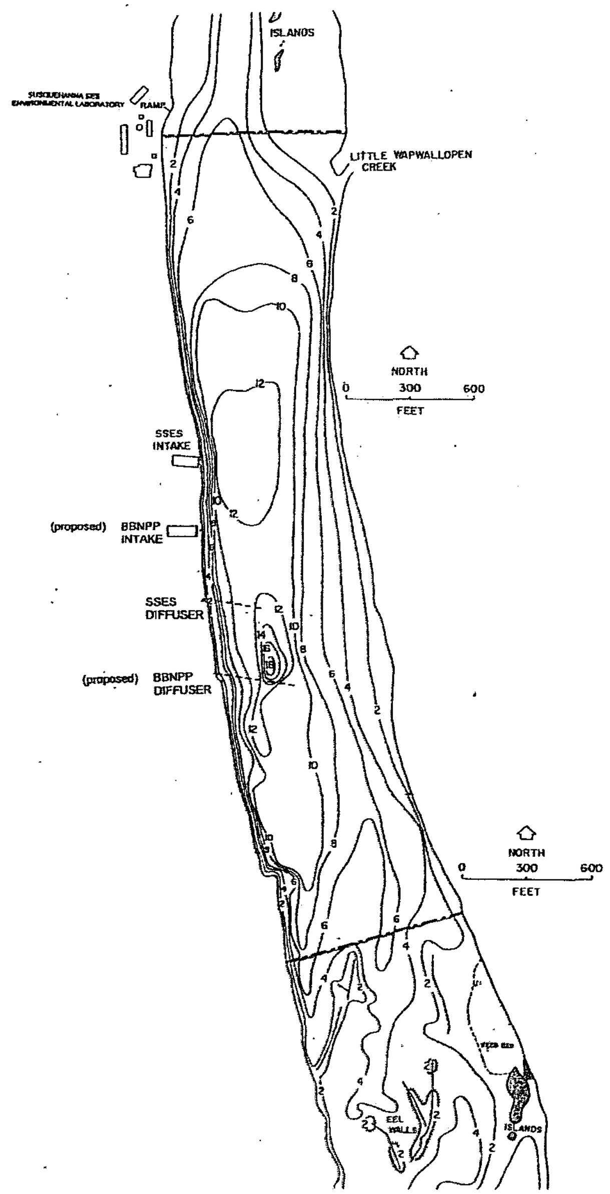
Full Text: The bathymetry of the Susquehanna River is provided as feet above mean sea level. The text indicates that the riverbed elevations near the intake range from 473 to 484 ft. Figure 2.3-11 shows the contour range at the intake site to be from 476 to 490 ft. The 473 ft contour is a small area about 200 ft south of the proposed intake site. The depth of the discharge listed in Ch. 3 differs from that in Ch. 2.

Response: Ichthyological Associates' report provides a figure (Figure 1) showing the depth contours in the vicinity of the intake and discharges structures. Depth contours are based on a river level at 486.2 ft above mean sea level (msl) surveyed in 1983. Figure 1 follows.

Reference cited in response: Ichthyological Associates, 1984. *Ecological Studies of the Susquehanna River In the Vicinity of the Susquehanna Steam Electric Station*, 1983 Annual Report, prepared for Pennsylvania Power and Light Company, August 1984.

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

Figure 1



Reference: Ichthyological Associates, Inc., 1984.

Note: Location of the Susquehanna Steam Electric Station (SSES) and the proposed Bell Bend Nuclear power Plant (BBNPP) river water intakes and discharge diffusers along the west bank of a pool in the Susquehanna River, six miles upriver from Berwick, PA, 2008. Depth contours at 2-foot intervals based on a river level at 486.2 feet above mean sea level surveyed in 1983.

STO 2.3-1

ESRP 2.3

Summary: *Provide the location of the disposal site for excess excavated material (soils), the planned routes for transporting the excess material and any upgrades necessary for these routes, and any planned measures for erosion control and stabilization of the disposal site at project completion.*

Full Text: Identify the proposed disposal site, which needs to be large enough to dispose of approximately 3 million cubic yards of excavated material.

Response: Location: Figure 1-1 is attached which shows four existing solid waste disposal areas, each of which can take over 3.5 million cubic yards of waste material. The landfills shown are:

- Commonwealth Environmental Systems
- Alliance Sanitary Landfill
- Phoenix Resources, Inc.
- Westmoreland Waste LLC Sanitary Landfill

Each of these landfills can potentially be used to dispose of any excess topsoil, soil spoils, or rock spoils that will be removed from the site. Showing the locations of these landfills does not represent a commitment to place waste in any one of them. The locations merely represent locations where excess soil or contaminated soil from the site may be placed.

Transportation: The landfills shown on Figure 1-1 are existing, and public roads lead to each of the sites. The spoils materials from the site will be transported on existing public roads to the landfill or landfills used. Upgrades or maintenance of the roads to each site would be decided by a state or local agency. The locations and route to each landfill are:

1. Commonwealth Environmental Systems: Location is 99 Commonwealth Road, Schuykill, Pa. From the site to the landfill, take N. Market St. to US-11 to PA 93 to I-80. Then take I-80 to I-81 to PA 25 to the landfill. The driving distance is 52 miles.

2. Alliance Sanitary Landfill: Location is 398 S. Keyser Ave., Taylor, Pa. From the site take N. Market St. to US11. Travel northeast on US11 to Union St. to S. Keyser Ave to the landfill. Union St. is near Scranton, Pa. The driving distance is 45 miles.

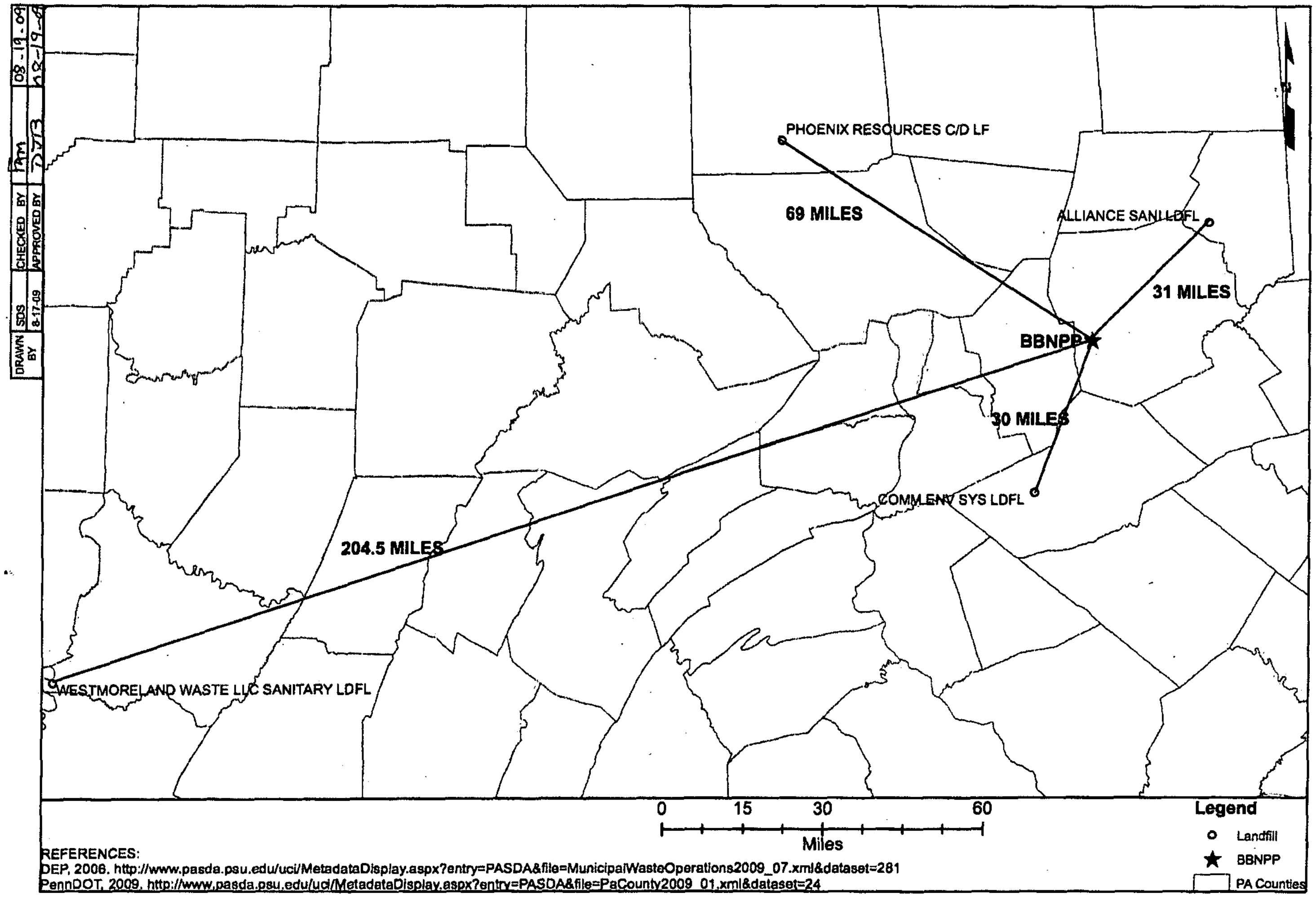
3. Phoenix Resources Landfill: Location is 782 Antrim Road, Wellsboro, Pa. From the site take N. Market St. to US 11 to I-80, to I-180 to US 15. At US 15 turn off on Grand Army of the Republic (US-6) to Charleston St. to Fellows Ave to Wetmore St. to Antrim St. to the landfill. The driving distance is 113 miles. This landfill would not be used unless the Numbers 1 and 2 are full.

4. Westmoreland Waste LLC Sanitary Landfill: Location is 1428 Delbert Drive, Monongahela, Pa. Take US 11 to I-80 to I-99 to US 22 to PA66 to I-70. Get off of I-70 on PA51 to PA136 to Delbert Drive to the landfill. The driving distance is 241 miles. This landfill would not be used unless the others are full.

Erosion Control: For a site to be approved it must file an erosion control plan, a soil stabilization plan, a long term care plan, and a closure plan. Each of the sites is existing and open to the public, so each site should have these plans filed and approved.

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

FIGURE 1-1
LANDFILLS IN PA WITH CAPACITY FOR 3.5 MILLION CUBIC YARDS



REFERENCES:
DEP, 2006. http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=MunicipalWasteOperations2009_07.xml&dataset=281
PennDOT, 2009. http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaCounty2009_01.xml&dataset=24

H 3.4-1

ESRP 3.4.1

Summary: *Provide Sargent & Lundy Report SL-009459 on the raw water system.*

Full Text: Staff needs quantitative information on the operation of the BBNPP intake structure, including the quantity and type of chemicals to be used for de-fouling, the de-icing procedures, and debris clearing operations for the trash rack.

Response: S&L Report No. SL-009459, Rev. 2 is available in the Bell Bend Electronic Reading Room.

Information on the intake structure (including chemical treatment, de-icing procedures, and trash rake debris clearing) is discussed in S&L Report No. SL-009498 Rev. 4, also available in the Bell Bend Electronic Reading Room.

The intake structure has a maximum withdrawal rate from the Susquehanna River of 31,709 gpm (CWS makeup flow = 23,808 gpm, maximum Raw Water Supply System [RWSS] flow = 7,901 gpm).

Sodium hypochlorite is used as an oxidizing biocide to control microbiological fouling in the RWSS. Sodium Hypochlorite solution is injected at the intake structure near the RWSS pumps. Chemical feed is intermittent. The estimated annual consumption is 2,190 gallons per year. (See FSAR Section 10.4.5.2.2 and ER Section 9.4.2.3).

No treatment is provided at the intake structure for control of zebra mussels. There has been no sighting of zebra mussels along the Susquehanna River in the vicinity of the proposed BBNPP site as shown in the most recent USGS distribution map updated January 18, 2008. Zebra mussels were reported upstream of Great Bend in the Susquehanna River, 65 miles upriver of the BBNPP site in 2007 by the PADEP. Zebra mussels have also been discovered in Cowanesque Lake, Tioga County, Pennsylvania 170 miles upriver of the BBNPP site in 2007. If zebra mussels are encountered in the future, specific chemical feed system(s) can be installed at that time. (See ER Section 2.4.2.2.8 and ER Section 9.4.2.3)

De-icing at the intake structure is performed utilizing the warm retention basin discharge flow. A water level decrease in the intake structure due to potential icing conditions is detected by level instrumentation. Main Control Room (MCR) control and position indication of the discharge bypass valve are provided to allow remote alignment of the retention basin discharge to the intake structure for the prevention of ice-formation in the intake structure bays. The bypass flow is indicated in the MCR using a flow meter located downstream of the bypass valve. (See ER Section 3.4.1.3.2).

The accumulation of debris on the bar grating and trash rake are monitored and cleaning is performed as necessary. The debris clearing operations for the trash rake are to temporarily store the debris in the trash baskets at the intake structure and then to properly dispose of the debris offsite at a registered landfill. ER Section 5.5.1 states, "Debris (e.g., vegetation) collected on trash rakes and screens at the water intake structure would be disposed of as solid waste in accordance with the National Pollutant Discharge Elimination System (NPDES) and Pennsylvania waste regulations permits applicable at the time of operation."

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

H 5.2-1

ESRP 5.2.2

Summary: *Provide information on the statistical calculation of low flow conditions such as the 7 day once-in-10-year low flow (7Q-10). Discuss (in quantitative terms if possible) the effect on the estimate of non-stationarity of the measured flow rates.*

Full Text: The applicant presented a statistical analysis of the 7Q-10 flow rate in FSAR 2.4.11. Staff is reviewing the potential effects of non-stationarity of measured flow rates caused by factors such as increased water demand, regulation of flow by dams, and long-term climate cycles. Staff is also reviewing the relationship between low flows near the site and drought management plans for the Susquehanna River basin.

Response: The following paragraph from ER Section 5.2.2 - Water Use Impacts (Rev. 1), discusses consumptive water use from the Susquehanna River during periods of low flow:

> The mean discharge of the Susquehanna River at Wilkes-Barre is 12,800 ft^3/sec (362.5 m^3/sec) (i.e., 5,745,039 gpm (21,747,338 lpm)) and the 7-day, 10-year low flow (7Q10) rate is 890 ft^3/sec (25.2 m^3/sec) (i.e., 399,460 gpm (1,512,121 lpm)) for the post-regulation period, 1980 to 1996 (USGS, 2008). The volume of water that will be lost to evaporation and drift from the BBNPP cooling towers and ESWS cooling towers is less than 1% of the mean discharge of the Susquehanna River and approximately 4.3% of the 7Q10 low flow discharge. No measurable impact of consumptive water use on river discharge during normal flows is expected, and operation of the BBNPP will therefore have a SMALL impact on the availability of water from the Susquehanna River...

The mean discharge of 12,800 ft^3/sec and the 7-day, 10-year low flow (7Q10) of 890 ft^3/sec for the Susquehanna River at Wilkes-Barre (Reference Gage: USGS 01536500) specified above was calculated using flow data recorded from 1980 through 1996 and was obtained from the following reference:

> **USGS, 2008**. Low flow statistics for Pennsylvania streams, Website: http://pa.water.usgs.gov/pc38/flowstats/lowflow.ASP?WCI=stats&WCU;ID=2428, Date accessed: May 30, 2008.

A low flow analysis that included the calculation of low flow statistics (including the 7Q10, or $Q_{7,10}$) was incorporated into FSAR Section 2.4.11 - Low Water Considerations. Therefore, in addition to determining the low flow statistics for the entire period of record at the Wilkes-Barre gage station (1906 through 2006), the calculation was revised so that data from water years 1906 through 1941 and 1981 through 2006 were also evaluated separately, in order to determine the impacts associated with factors such as increased water demand and the regulation of flow by dams (1906 through 2006 = entire period of record, 1906 through 1941 = pre-regulation period / no upstream dams, 1981 through 2006 = post-regulation period). The calculated 7-day, 10-year low flows (7Q10, or $Q_{7,10}$) at Wilkes-Barre can be summarized as follows:

Calculated 7Q10 at Wilkes-Barre Gaging Station

Gage Station	Drainage Area [mi²]	Period of Record	$Q_{7,10}$ [cfs]	Mean [cfs]	Median [cfs]	Harmonic Mean [cfs]
Wilkes-Barre (upstream)	9,960	1906 - 2006	850	13,606	7,390	4,283
		1906 - 1941	908	12,618	6,540	3,880
		1981 - 2006	828	14,530	8,625	4,933

Since the difference between the low flow statistics for the "pre-regulation period" and "post-regulation period" is minimal, which is probably due to the fact that significant upstream dams were constructed to provide flood control and only two reservoirs (Stillwater and Cowanesque) provide water supply, it is concluded that there are no significant impacts associated with factors such as increased water demand and the regulation of flow by dams during low flow conditions in the Susquehanna River. By comparing the pre- and post-regulation period low flow statistics to those that were computed for the entire period of record (1906 to 2006), it can be concluded that the 7-day, 10-year low flow (7Q10, or $Q_{7,10}$) does not fluctuate significantly for different periods of record.

The calculation that supports the low flow statistics results can be found in Enclosure 3.

COLA Impact:
BBNPP COLA ER Section 5.2.2.1.1 will be revised as follows and Table 5.2-3 added in a future revision of the COLA:

5.2.2.1.1 Consumptive Use

The maximum evaporation and drift from the BBNPP CWS cooling towers is estimated to be approximately 15,880 gpm (60,106 lpm). Evaporation and drift from the ESWS cooling towers, during normal operations, are estimated to be 1,144 gpm (4,330 lpm). Minor consumptive losses of 40 gpm (151 lpm) are expected from various power plant systems.

Consumptive uses of water during construction of BBNPP include concrete mixing and curing, dust control, and potable and sanitary water. Peak consumptive water use will occur for several years during construction, and will be approximately 39 million gpy (149 million lpy). A breakdown of construction water use by year is provided in Table 5.2-2.

The mean discharge of the Susquehanna River at Wilkes-Barre is 12,800 ft^3/sec (362.5 m^3/sec) (i.e., 5,745,039 gpm (21,747,338 lpm)) and the 7-day, 10-year low flow (7Q10) rate is 890 ft^3/sec (25.2 m^3/sec) (i.e., 399,460 gpm (1,512,121 lpm)) for the post-regulation period, 1980 to 1996 (USGS, 2008).

In addition to determining the low flow statistics for the entire period of record at the Wilkes-Barre gage station (1906 through 2006), data from water years 1906 through 1941 and 1981 through 2006 were also evaluated separately, in order to determine the impacts associated with factors such as increased water demand and the regulation of flow by dams (1906 through 2006 = entire period of record, 1906 through 1941 = pre-regulation period / no upstream dams, 1981 through 2006 = post-regulation period). The calculated 7-day, 10-year low flows (7Q10, or $Q_{7,10}$) at Wilkes-Barre are summarized in Table 5.2-3.

Since the difference between the low flow statistics for the "pre-regulation period" and "post-regulation period" is minimal, which is probably due to the fact that significant upstream dams were constructed to provide flood control and only two reservoirs (Stillwater and Cowanesque) provide water supply, it can be concluded that there are no significant impacts associated with factors such as increased water demand and the regulation of flow by dams during low flow conditions in the Susquehanna River. By comparing the pre- and post-regulation period low flow statistics to those that were computed for the entire period of record (1906 to 2006), it can be concluded that the 7-day, 10-year low flow (7Q10, or $Q_{7,10}$) does not fluctuate significantly for different periods of record.

The volume of water that will be lost to evaporation and drift from the BBNPP cooling towers and ESWS cooling towers is less than 1% of the mean discharge of the Susquehanna River and approximately 4.3% of the 7Q10 low flow discharge. No measurable impact of consumptive water use on river discharge during normal flows is expected, and operation of the BBNPP will therefore have a SMALL impact on the availability of water from the Susquehanna River ~~(USGS, 2008)~~.

Table 5.2-3 Calculated 7Q10 at Wilkes-Barre Gaging Station

Gage Station	Drainage Area [mi²]	Period of Record	Q7,10 [cfs]	Mean [cfs]	Median [cfs]	Harmonic Mean [cfs]
Wilkes-Barre (upstream)	9,960	1906 - 2006	850	13,606	7,390	4,283
		1906 - 1941	908	12,618	6,540	3,880
		1981 - 2006	828	14,530	8,625	4,933

RHH 4.5-3

ESRP 4.5

Summary: *Explain the difference in the average results from the SSES environmental TLD data (20.8 mR) results and PaDEP SSES TLD data (44.1 mR) from 2004 (most recent PaDEP data available).*

Full Text: Need to understand the reason for the difference to properly evaluate the environmental dose impacts from SSES effluents, direct exposure from the ISFSI and onsite radioactive waste storage.

Response: The Pennsylvania Department of Environmental Protection/Bureau of Radiological Protection (PaDEP/BRP) TLD data are raw data standardized to a calendar month, based on time in the field less the transit dose data, which results in a net exposure (dose) value. When PaDEP/BRP TLD's are shipped to the vendor Global Dosimetry Services in California for processing a TLD accompanies the field TLD's to determine transit dose. The resulting values are what is documented in the attached Table 5B as "Annual Dose" for each location and the resultant Annual Average for all the sites.

The PPL Susquehanna Steam Electric Station (SSES) TLD values reported in the SSES's 2004 Radiological Environmental Monitoring Program (REMP) report Table I-1, Environmental TLD Results consist of the raw data for each location that are normalized to a standard calendar quarter. These raw data are used to calculate Indicator and Control location exposure values for each quarter. The 2004 SSES TLD program data represents 58 locations (48 indicator, 5 control, and 5 special interest areas).

The PaDEP/BRP 2004 Annual Average value of 44.1 mR and the SSES REMP value of 20.8 mR (which is the Indicator Average for the 1st Qtr. 2004) cannot be compared because the calculation methodologies are completely different. The data sets are not identical since the PA DEP/BRP Table 5B has 30 locations and only 17 were co-located with SSES TLD locations.

The attached 2004 table SSES REMP TLD Co-Located Sites with PaDEP/BRP, compares TLD data at the seventeen sites where both PaDEP/BRP and PPL SSES TLDs are located. Based on a comparison of the data, the average annual exposure at these sites shows that the PPL data are 76.5 mR/year while the PaDEP data are 44.0 mR/year. The reasons for this difference are many.

To compare PPL and PaDEP/BRP environmental TLD results, the two TLD system performance metrics must be normalized to address the procedure/algorithm used to account for: transit dose, self-dosing, glow-curve, fading control TLD correction, background subtraction for net analysis, and data anomalies. This means two system performance metrics must be similar in order to produce results to the same degree of reliability.

The two TLD programs are set up to only compare trends between the PPL and PaDEP/BRP data. It is the change within a system that is determined, not a 1-to-1 comparison at any given time.

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

5.B

SUSQUEHANNA STEAM ELECTRIC STATION
THERMOLUMINESCENCE DOSIMETRY (TLD) DATA
(mR/std. mo.)

Location	1/7/04 to 4/1/04	4/1/04 to 7/1/04	7/1/04 to 10/7/04	10/7/04 to 1/4/05	Annual Dose
01D1 Mocanaqua	3.7 +/- 0.6	3.4 +/- 0.3	4.4 +/- 0.1	4.2 +/- 0.4	47.2 +/-2.5
02A1 InformationCenter	3.7 +/- 0.7	3.3 +/- 0.2	3.6 +/- 0.7	3.3 +/- 1.2	41.7 +/-4.7
03D1 Pond Hill	4.1 +/- 0.8	3.1 +/- 0.1	3.5 +/- 0.7	3.8 +/- 0.8	43.9 +/-4.1
03K1 Nanticoke	4.0 +/- 0.4	3.0 +/- 0.4	3.5 +/- 0.8	3.4 +/- 1.1	41.6 +/-4.4
03M1 Wilkes-Barre	4.3 +/- 0.2	3.3 +/- 0.3	4.2 +/- 0.2	4.0 +/- 0.6	47.7 +/-2.1
04A1 PP&L Construction Dept.	3.9 +/- 0.4	3.2 +/- 0.1	4.0 +/- 0.5	3.6 +/- 1.0	44.2 +/-3.4
04E1 Ruckles Hill Road	3.6 +/- 0.7	3.5 +/- 0.4	4.0 +/- 0.4	3.8 +/- 0.7	44.9 +/-3.3
05A1 Biological Lab	3.5 +/- 1.0	2.7 +/- 0.5	3.4 +/- 0.8	3.2 +/- 1.2	38.5 +/-5.6
05E1 Bloss Farm	4.4 +/- 1.6	3.2 +/- 0.1	4.0 +/- 0.3	3.8 +/- 0.8	46.3 +/-5.6
06A1 SSES Sewage Plant	3.5 +/- 0.8	3.1 +/- 0.2	3.7 +/- 0.6	3.4 +/- 1.1	41.2 +/-4.5
06A2 River Water Intake	3.7 +/- 0.6	3.0 +/- 0.2	3.5 +/- 0.8	3.3 +/- 1.3	40.4 +/-4.8
06D1 Hobbie	3.3 +/- 1.0	3.2 +/- 0.4	3.9 +/- 0.5	3.8 +/- 0.8	42.4 +/-4.3
06L1 Freeland	3.7 +/- 0.6	4.3 +/- 1.1	4.6 +/- 0.4	4.9 +/- 0.3	52.9 +/-4.0
07B1 Wapwallopen	3.2 +/- 1.1	3.2 +/- 0.1	3.8 +/- 0.5	4.0 +/- 0.7	42.4 +/-4.1
07B2 Heller's Orchard	3.7 +/- 0.8	3.0 +/- 0.2	3.4 +/- 0.8	4.6 +/- 1.3	44.1 +/-5.2
07L1 Hazelton	3.2 +/- 1.1	3.2 +/- 0.3	3.6 +/- 0.7	3.9 +/- 0.7	41.8 +/-4.5
09B1 South Transmission Line	3.1 +/- 1.1	2.8 +/- 0.3	3.5 +/- 0.7	2.8 +/- 1.7	36.6 +/-6.4
09M1 Shenandoah	2.8 +/- 1.4	2.6 +/- 0.5	3.2 +/- 1.0	3.2 +/- 1.3	35.2 +/-6.8
10B1 Beach Haven/Gen Tank	3.2 +/- 1.0	3.0 +/- 0.2	Missing	3.6 +/- 1.0	29.4 +/-4.2
11A1 Golomb House	3.4 +/- 0.9	3.3 +/- 0.2	4.2 +/- 0.4	3.9 +/- 0.8	44.0 +/-3.8
11F1 Nescopeck	3.3 +/- 0.9	3.0 +/- 0.2	4.9 +/- 1.3	3.8 +/- 0.8	45.0 +/-5.4
12A1 WSW Perimeter Fence	5.0 +/- 0.7	3.8 +/- 0.8	4.4 +/- 0.3	5.3 +/- 0.8	55.5 +/-4.1
12F1 Berwick Substation	4.4 +/- 0.2	3.1 +/- 0.2	3.5 +/- 0.8	3.7 +/- 0.9	44.1 +/-3.6
12L1 Bloomsburg	3.2 +/- 1.1	2.8 +/- 0.3	3.6 +/- 0.6	3.3 +/- 1.2	38.6 +/-5.2
13A1 West Perimeter Fence	4.0 +/- 0.4	4.0 +/- 0.7	4.5 +/- 0.2	4.6 +/- 0.1	51.1 +/-2.6
14A1 WNW Perimeter Fence	4.3 +/- 0.1	3.3 +/- 0.4	4.8 +/- 1.8	4.0 +/- 0.6	49.3 +/-5.8
15A1 Serafin Farm	3.1 +/- 1.1	3.6 +/- 0.4	3.8 +/- 0.6	3.8 +/- 0.9	42.9 +/-4.7
16A1 NNW Perimeter Fence	4.9 +/- 0.7	4.1 +/- 0.9	4.7 +/- 0.3	4.9 +/- 0.3	55.8 +/-3.7
16A2 Rupinski Farm	2.8 +/- 1.4	3.1 +/- 0.0	3.2 +/- 1.0	3.9 +/- 0.7	38.9 +/-5.6
16B1 Walton Power Line	3.7 +/- 1.0	2.9 +/- 0.3	8.2 +/- 7.9	3.6 +/- 1.0	55.1 +/-24.2
*Control corrected-net exposure.				Annual Average:	44.1 +/-5.1

TABLE I-1
ENVIRONMENTAL THERMOLUMINESCENT DOSIMETRY RESULTS
SUSQUEHANNA STEAM ELECTRIC STATION - 2004
Results (1) are in mR/std. qtr (2) ± 2S (3)

Location	First Quarter 01/27/04 to 04/23/04	Second Quarter 04/21/04 to 07/21/04	Third Quarter 07/20/04 to 10/27/04	Fourth Quarter 10/26/04 to 01/26/05
10-20 MILES				
3G4	21.2 ± 2.0	20.0 ± 1.6	19.3 ± 1.2	23.5 ± 2.0
4G1	22.8 ± 2.2	21.1 ± 1.8	19.3 ± 1.3	23.6 ± 1.0
6G1	22.2 ± 1.1	(8)	(8)	(8)
7G1	18.9 ± 1.1	18.4 ± 1.6	17.3 ± 1.4	21.0 ± 1.4
7G2	18.9 ± 1.1	(8)	(8)	(8)
8G1	17.2 ± 1.3	(8)	(8)	(8)
12G1	17.5 ± 0.9	17.9 ± 1.0	16.0 ± 0.5	18.9 ± 1.8
12G4	20.7 ± 1.3	20.2 ± 0.6	19.3 ± 2.3	22.1 ± 1.4

See the comments at the end of this table.

Location				
Indicator Average (6)	20.8 ± 12.8	21.2 ± 12.6	19.9 ± 12.3	23.2 ± 12.6
Control Average (6)	19.9 ± 4.1	19.5 ± 3.1	18.2 ± 3.3	21.8 ± 3.5

COMMENTS

(1) Individual monitor location results are normally the average of the elemental doses of six calcium elements from the two TLDs assigned to each monitoring location.

(2) A standard (std.) quarter (qtr.) is considered to be 91.25 days. Results obtained for monitoring periods of other durations are normalized by multiplying them by 91.25/x, where x is the actual duration in days of the period.

(3) Uncertainties for individual monitoring location results are two standard deviations of the elemental doses of six calcium elements from the two TLDs assigned to each monitorin glocation, representing the variability between the elemental doses of each of the six TLD elements.

(4) TLDs were not in the field at this monitoring location during this quarter. Refer to Appendix A of this report for an explanation of program changes to the REMP.

(5) No measurement could be made because the TLDs were lost, stolen or damaged.

(6) Uncertainties associated with quarterly indicator and control averages are two standard deviations, representing the variability between the results of the individual monitoring locations.

(7) Data were invalidated for this period because of an unacceptably high coefficient of variation among element readings (not applicable for 2004 data).

(8) Extra TLDs, not required by TRM/ODCM (i.e. do not provide additional benefit) and were deleted from the monitoring program.

2004
SSES REMP TLD CO-LOCATED SITES WITH PADEP/BRP

PA DEP Site		PA DEP Annual Exposure *(Raw Data) (mr/year)	SSES Site Location	SSES Annual Exposure **(Raw Data) (mr/year)	
02A1	InformationCenter	41.7	2S2	78.4	
05A1	Biological Lab	38.5	5S4	67.6	
12A1	WSW Perimeter Fence	55.5	12S3	99.7	
13A1	West Perimeter Fence	51.1	13S2	101.5	
14A1	WNW Perimeter Fence	49.3	14S5	89.3	
16A1	NNW Perimeter Fence	55.8	16S1	90.5	
15A1	Serafin Farm	42.9	**15A3**	**59**	SSES Data missing 1 qtr.
16A2	Rupinski Farm	38.9	**16A2**	**51.9**	SSES Data missing 1 qtr.
07B1	Wapwallopen	42.4	8B2	72.8	
09B1	South Transmission Line	36.6	9B1	69.7	
10B1	Beach Haven/Gen Tank	29.4	10B3	70.4	
01D1	Mocanaqua	47.2	**1D5**	**60.3**	SSES Data missing 1 qtr.
04E1	Ruckles Hill Road	44.9	4E2	80.8	
05E1	Bloss Farm	46.3	5E2	78.7	
03M1	Wilkes-Barre	47.7	3G4	84	
07L1	Hazleton	41.8	7G1	75.6	
12L1	Bloomsburg	38.6	12G1	70.3	
	Annual Average Exposure	**44.0**		**76.5**	

* PA DEP/BRP Raw data from Table 5.B
** PPL Raw data from 2004 Annual Radiological Environmental Operating Report.
Raw data is incorporated into a calculation to determine member of the public exposure due to station operations.
Reference PPL Calculation EC-ENVR-1012 Rev. 0 for determination of dose due to station operations in 2004.

SE 4.4-3

<u>ESRP 4.4.2</u>

Summary: *Provide consistent in-migration values in percentage terms in Section 4.4.2.*

Full Text: In Section 4.4.2, the ER presents an upper and lower limit on the in-migration value in percentage terms (20-35 percent). These rates differ significantly. Identify a single best estimate and use it as the basis of each calculation that falls out of the analysis – e.g., impacts on local schools, tax impacts.

Response: Evaluation of the potential socioeconomic impact of in-migration in the Bell Bend Environmental Report is based on two scenarios. In-migration scenarios of 20% and 35% were selected because they are representative of the range of in-migration levels that the NRC found in studies conducted in 1981 of nuclear power plant construction workforces. The NRC conducted a study (NRC, 1981) of 28 surveys of construction workforce characteristics for 13 nuclear power plants. They found that 17% to 34% of the total construction workforces at most of these nuclear power plants (the 75th percentile) had moved their families into the study areas for each power plant (see ER Section 4.4.2 for further information regarding this study). The rationale for the use of the two bounding scenarios is elaborated in ER Section 4.4.2.1. A review of previously submitted ERs shows that estimates as high as 50% in-migration have been used as an assumption. One ER cited a survey that determined in-migration to be slightly less than 50%, but then inflated the number to 50% to provide conservatism. Based on these findings and the 1981 study conducted by the NRC, PPL believes that representing in-migration as a range between 20% and 35% provides a reasonable and supportable bounding of the potential for in-migration.

The general conclusion based on the in-migration analysis is that there would be a net economic benefit from the construction and operation of the BBNPP facility. To the degree that a single point estimate of approximately the same magnitude was used, it would not change this conclusion.

Reference cited in response: NRC, 1981. NUREG/CR-2002, PNL-3757, Volume 2, Migration and Residential Location of Workers at Nuclear Power Plant Construction Sites, Profile Analysis of Worker Surveys. Prepared for the U.S. Nuclear Regulatory Commission, Washington, D.C. Prepared by S. Malhotra and D. Manninen, Pacific Northwest Laboratory.

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

SE 4.4-12

ESRP 4.4.2

Summary: Refine the estimated number of children per household based on available SSES work force data.

Full Text: In the ER, the total number of children per household is calculated by dividing the number of children in Pennsylvania by the number of households. Because the demographics of the construction workforce households would differ from statewide averages (there are retired households included in the statewide average), the number of children per household should be adjusted based on available SSES work force data or other data reflecting the expected demographics of the construction workforce.

Response: RAI SE 4.4-12 suggests that using the SSES family size is a more appropriate measure of the number of children in the construction workforce than the overall Pennsylvania (PA) state census data average, because the PA data are likely to contain a higher percentage of retired persons. The argument would be that a construction work force, like that of the SSES employees, would have a higher percentage of children and fewer retirees. Table 1 below suggests that: 1) mean family (includes a householder and one or more other persons living in the same household who are related to the householder by birth, marriage, or adoption) and household (includes all of the people who occupy a housing unit) size across the state is higher than that within the two local towns and the ROI counties; and, 2) that the percent of households with children under 18 years of age across the state is slightly higher than within the ROI or the local towns. Further the data suggest that the difference in the number of family members among the various jurisdictions is so small that modifying the existing approach will not affect the overall conclusion with respect to the impact on school capacity or other social services. However, the use of the Pennsylvania average number of students per household is conservative, assuming, as the RAI implies, that the in-migrating workforce family structure is most similar to that found where most of the SSES workers reside, i.e., the ROI where the number of children under 18 is slightly lower than the state average.

Reference cited in response: USCB, 2009. U.S. Census Bureau, American Fact Finder Fact Sheets, 2000 and 2005-2007. American Community Survey 3-year Estimates. Website: http://facfinder.cusnsus.gov. Date Accessed 20 August , 2009.

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

Table 1

Summary of mean household and mean family size comparing Pennsylvania, the two ROI counties and the two local towns adjacent to the proposed Bell Bend Nuclear Power Plant

Census Year	**2005-07**	**2005-07**	**2000**	**2000**	**2000**
	Mean Household	Mean Family	Mean Household	Mean Family	% of Households with children under age 18
Luzerne County	2.33	2.94	2.34	2.95	19.3
Columbia County	2.36	2.80	2.42	2.90	19.2
PA	2.46	3.04	2.48	3.04	21.6
Salem Township			2.45	2.87	20.6
Berwick			2.28	2.90	20.6

Source: USCB, 2009

TE 4.3-9

ESRP 4.3.1

Summary: *Provide a figure showing the locations proposed for storage of dredge and fill materials.*

Full Text: None.

Response: Figure 3.4-3 is provided to show a temporary dredge pond. Dredge spoils are pumped into the pond, the spoils settle out, and the excess water drained off and discharged back to the river. The water will meet the requirements of the PaDEP before being released. After the dredging is completed, the entire dredge pond will be removed, and the pond and dredge spoils hauled to a solid waste disposal area. The temporary dredge pond area will be returned back to its original state.

Figure 1-1 is provided to show where the potential disposition of any excess topsoil, soil spoils, or rock spoils from the site excavation and grading can be placed. The landfills shown are:

- Commonwealth Environmental Systems
- Alliance Sanitary Landfill
- Phoenix Resources, Inc.
- Westmoreland Waste LLC Sanitary Landfill

Each of the four landfills shown has a capacity of over 3.5 million cubic yards of solid waste. Showing the locations of these landfills does not represent a commitment to place waste in any one of them. The locations merely represent locations where excess soil or contaminated soil from the site may be placed.

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

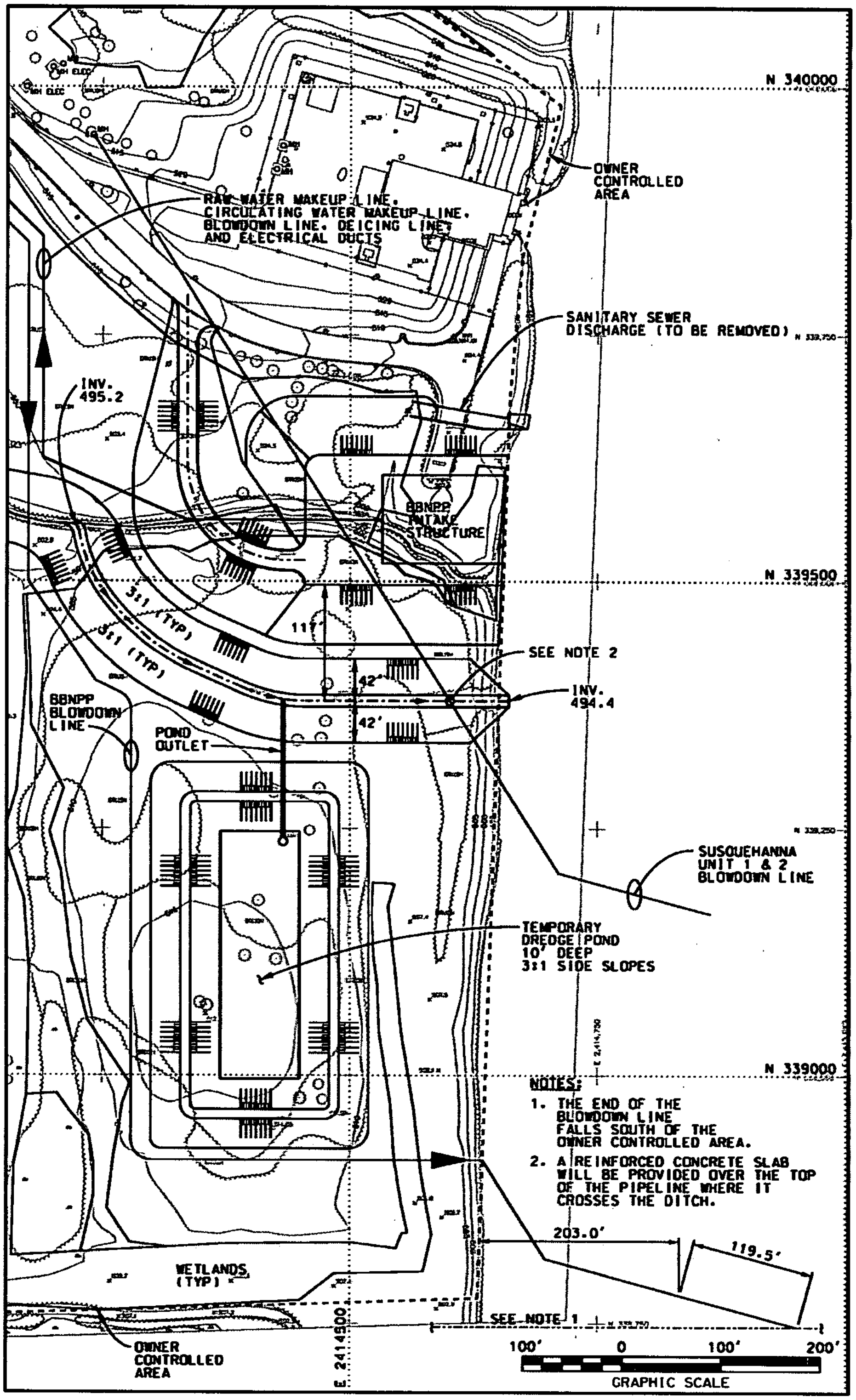
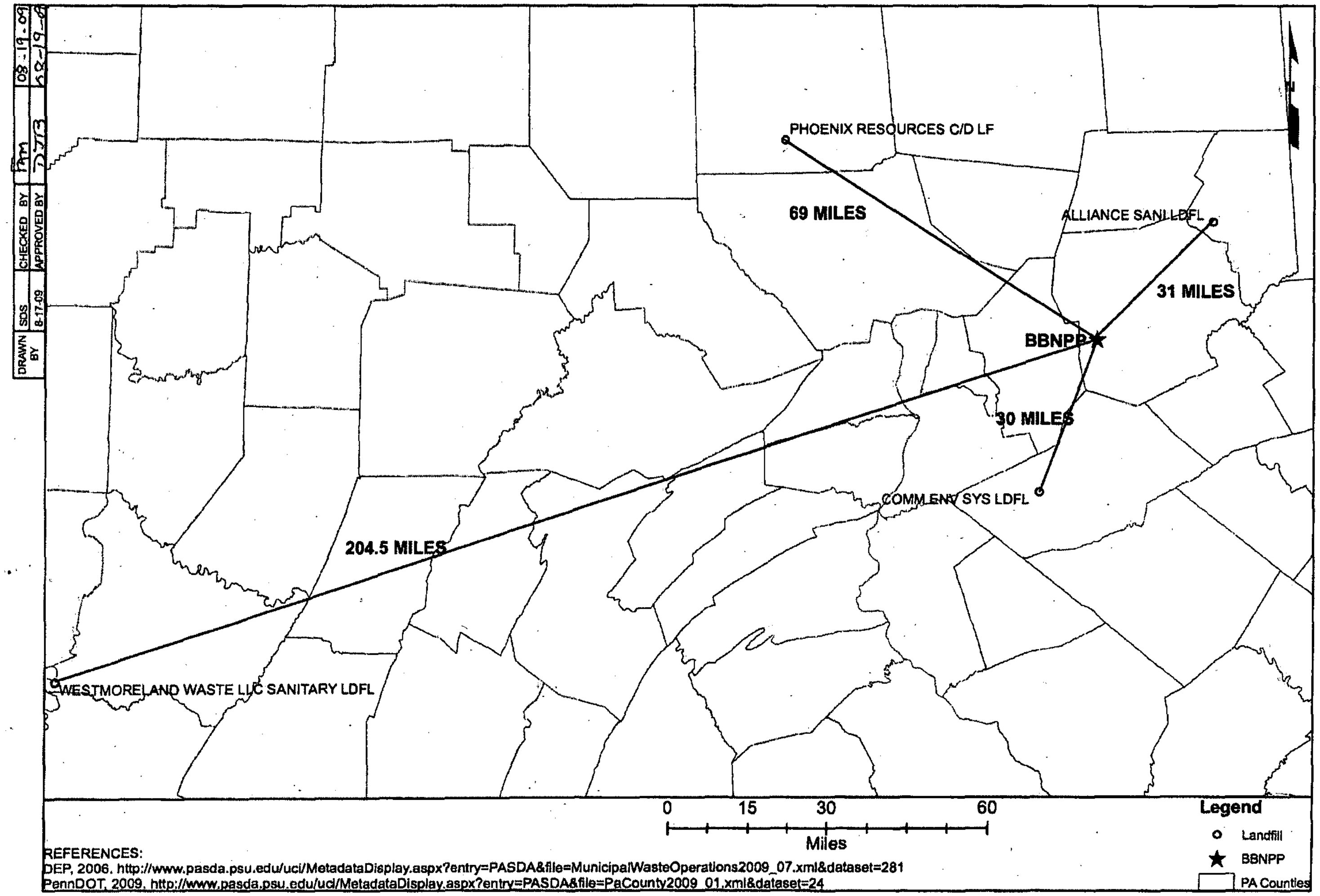

N 340000
OWNER CONTROLLED AREA
RAW WATER MAKEUP LINE, CIRCULATING WATER MAKEUP LINE, BLOWDOWN LINE, DEICING LINE, AND ELECTRICAL DUCTS
SANITARY SEWER DISCHARGE (TO BE REMOVED)
INV. 495.2
BBNPP INTAKE STRUCTURE
N 339500
3:1 (TYP)
3:1 (TYP)
117'
SEE NOTE 2
42'
42'
INV. 494.4
BBNPP BLOWDOWN LINE
POND OUTLET
SUSQUEHANNA UNIT 1 & 2 BLOWDOWN LINE
TEMPORARY DREDGE POND 10' DEEP 3:1 SIDE SLOPES
N 339000
NOTES:
1. THE END OF THE BLOWDOWN LINE FALLS SOUTH OF THE OWNER CONTROLLED AREA.
2. A REINFORCED CONCRETE SLAB WILL BE PROVIDED OVER THE TOP OF THE PIPELINE WHERE IT CROSSES THE DITCH.
203.0'
119.5'
WETLANDS (TYP)
SEE NOTE 1
OWNER CONTROLLED AREA
E 2414500
100' 0 100' 200'
GRAPHIC SCALE

FIGURE 3.4-3

FIGURE 1-1
LANDFILLS IN PA WITH CAPACITY FOR 3.5 MILLION CUBIC YARDS



REFERENCES:
DEP, 2006. http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=MunicipalWasteOperations2009_07.xml&dataset=281
PennDOT, 2009. http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaCounty2009_01.xml&dataset=24

TR 4.7-1

ESRP 4.7

Summary: *Provide a conversion of the quantities of construction material for cable and piping to linear feet from the Table in RFI-06-032 that lists these materials in tons*

Full Text: None.

Response: It is estimated that 585,277 linear feet (178,392 meters) of large and small bore pipe will be required for the BBNPP project. As a basis for establishing Traffic Impact, RFI-06-032 stated that shipments of large and small bore pipe would total 7,500 tons (15 million pounds [6,804,000 kilograms]). The conversion for piping is 25.62 pounds per linear foot (38.13 kilograms per meter).

It is estimated that 10,495,611 linear feet (3,199,062 meters) of cable will be required for the BBNPP project. RFI-06-32 stated that shipments of Power and Control Wire would amount to 4,406 tons (8.81 million pounds [3,996,216 kilograms]). The conversion for cable is 0.8396 pounds per linear foot (1.25 kilograms per meter).

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

USACE-2g

Summary: *Provide a vicinity map and plan for the disposal options for any excess fill material resulting from construction.*

Full Text: Under 33 CFR 325.1 (Applications for permits) as well as under the 404 (b)(1) Guidelines, all disposal areas need to identified and in compliance with 230.10 and 230.11.

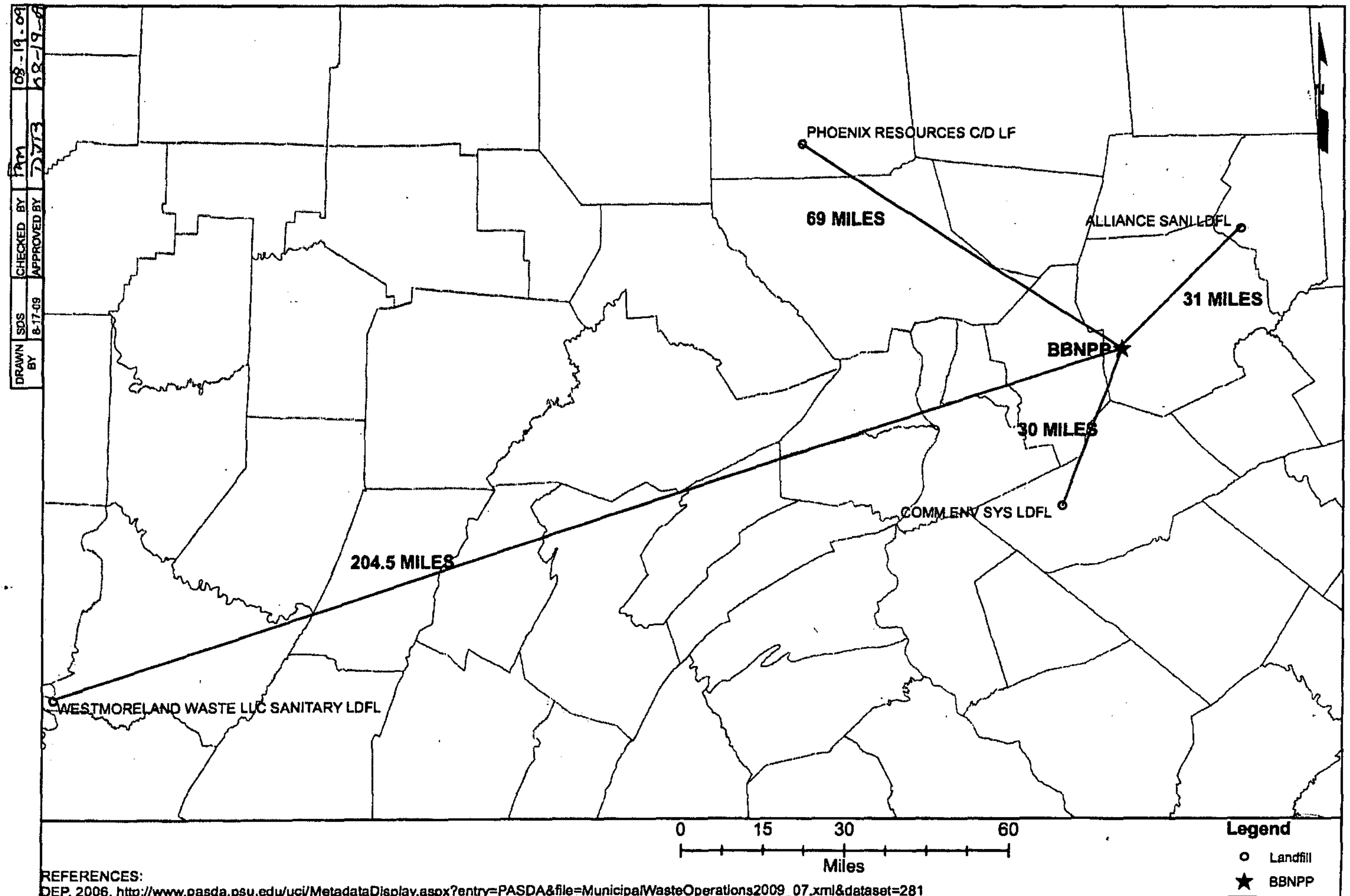
Response: Location: Figure 1-1 is attached and shows four existing solid waste disposal areas, each of which can take over 3.5 million cubic yards of waste material. The landfills shown are:

- Commonwealth Environmental Systems
- Alliance Sanitary Landfill
- Phoenix Resources, Inc.
- Westmoreland Waste LLC Sanitary Landfill

Each of these landfills can potentially be used to dispose of any excess topsoil, soil spoils, or rock spoils that will be removed from the site. Showing the locations of these landfills does not represent a commitment to place waste in any one of them. The locations merely represent locations where excess soil or contaminated soil from the site may be placed.

COLA Impact:
No changes to the BBNPP COLA ER are required as a result of this RAI response.

FIGURE 1-1
LANDFILLS IN PA WITH CAPACITY FOR 3.5 MILLION CUBIC YARDS



REFERENCES:
DEP, 2006. http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=MunicipalWasteOperations2009_07.xml&dataset=281
PennDOT, 2009. http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaCounty2009_01.xml&dataset=24

Enclosure 3

RAI H 5.2-1 Calculation
Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2)
September 18, 2009
Bell Bend Nuclear Power Plant
Luzerne County Pennsylvania

DW = David Wallner David Wallner
FAM = Fehmida Mesania Fehmida Mesania

Purpose:

1. Develop a frequency distribution (or determine the recurrence interval) of low flow events, which could potentially have an adverse impact on the Bell Bend site, based on historic USGS daily flow data recorded at the Wilkes-Barre and Danville gage stations along the Susquehanna River (immediately upstream and downstream from the site, respectively).

2. Estimate low flow statistics $Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$ based on historical USGS flow data recorded at Wilkes-Barre and Danville gage stations.

3. Low flow statistics including the $Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$ will also be transferred from the upstream and downstream gages to the ungaged site using drainage area ratios (DA_{site}/DA_{gage}) as suggested by the USGS and PaDEP. These analyses will estimate both the recurrence interval and impact of localized drought events.

Assumptions:

When transferring the low flow statistics ($Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$) from the upstream and downstream gages to the ungaged site, the following assumptions were made:

- The ungaged drainage area at the site is hydrologically similar to the upstream and downstream gage drainage areas at Wilkes-Barre and Danville, respectively.

- Multiplying any gage low flow statistic by the associated drainage area ratio provides a good estimate of that particular statistic across the site drainage area so long as the drainage area ratio is within the maximum suggested range of 1/3 to 3 as suggested by the USGS and PaDEP (see ***Reference 3***).

Methodology:

Low flow recurrence intervals will be estimated using three (3) different frequency distribution techniques: Weilbull, Gumbel, and log Pearson Type III. Low flow statistics calculated at the upstream and downstream gage stations will be transferred to the site using drainage area ratios as proposed by the USGS and PaDEP (see ***Reference 3***).

Input:

USGS daily streamflow data for Wilkes-Barre (USGS 01536500) and Danville (USGS 01540500) gage stations.

References:

USGS Streamflow Data Website: http://waterdata.usgs.gov/, date accessed: 3/19/2008, daily streamflow data for Wilkes-Barre (USGS 01536500) and Danville (USGS 01540500) gage stations.

Linsley, Ray K., J.B. Franzini, D.L. Freyberg, and G. Tchobanoglous, 1992, "Probability Concepts in Planning," Water-Resources Engineering, B.J. Clark and E. Castellano, ed., 4th ed., McGraw-Hill, Inc., New York, pp. 140-144 and pp. 808-809 (Table A-5). (Attached as "***Reference 1***")

SSES NPP FSAR Report, Rev. 46, Figure 2.4-6, 06/93. (Attached as "***Reference 2***")

"Computing Low-Flow Statistics for Ungaged Locations on Pennsylvania Streams By Use of Drainage-Area Ratios," http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf, date accessed: 3/27/2008. (Attached as "***Reference 3***")

Electronic File Locations:

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre Daily Flow Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville Daily Flow Data

Calculations:

1. Low Flow Frequency Distributions

   All of the frequency distribution techniques that are developed in this calculation to estimate the recurrence intervals associated with low flow events at each gage station are more commonly used to estimate flood event frequencies. However, by adjusting the procedure slightly to accommodate for low flow events when calculating the Weilbull recurrence intervals to establish an estimated frequency distribution, and by calculating the probability that the flow is *less than* (as opposed to greater than or equal to) a flow event of a given magnitude (instead of solving for P, solving for 1 – P) when developing the other frequency distributions, all three (3) methods can be used effectively to estimate the frequencies of low flow events.

a. Weilbull Frequency Distribution:

When considering all three distribution methods being used to conduct this low flow frequency analysis, the Weilbull distribution has the most basic approach when it comes to estimating low flow recurrence intervals. Annual low flows taken from USGS daily flow data are simply arranged in ascending order based on their magnitude with the lowest flow on record being first, and the recurrence interval is calculated based on how the low flow ranks among all other flows within the period of record. The Weilbull formula for recurrence interval estimation is given below, and the calculated return periods corresponding to the low flows recorded at each gage station (Wilkes-Barre and Danville) can be found in ***Attachment A***. For additional information regarding this approach, see ***Reference 1***. Note that the Weilbull procedure described above has been adjusted for low flow; the procedure given in ***Reference 1*** is for peak flow.

$$P := \frac{1}{T_r}$$ (Equation 1) (Ref. 1: Eq. 5.2)

$$T_r := \frac{N + 1}{m}$$ (Equation 2) (Ref. 1: Eq. 5.1)

P = probability of occurrence.
N = period of record.
m = *m*th smallest flow in data series.
T_r = recurrence interval.

b. Gumbel Frequency Distribution:

Developed under the argument that the distribution of flows within a given area is unlimited, the Gumbel distribution incorporates more advanced statistical applications in its projection of recurrence intervals for various low flow events. The probability of a flow of lesser magnitude occurring is calculated based on a factor "b" as shown in the equations below, and the corresponding recurrence interval is taken as the inverse of the probability of occurrence ($T_r = 1 / P$). The frequency calculations made using the Gumbel approach can be found in ***Attachment A***; for any additional information consult ***Reference 1***. Note that Equation 3 has been adjusted for low flow; the equation given in ***Reference 1*** is for peak flow (probability that a flow of equal or greater magnitude occurs).

$$P := 1 - \left(1 - e^{-e^{-b}}\right)$$ (Equation 3) (Ref. 1: Eq. 5.4)

$$b := \frac{1}{0.7797 \cdot \sigma_x} \cdot \left(X - X_{bar} + 0.45 \cdot \sigma_x\right)$$ (Equation 4) (Ref. 1: Eq. 5.5)

$$\sigma_x := \left(\frac{\Sigma\left(X - X_{bar}\right)^2}{N - 1}\right)^{\frac{1}{2}}$$ (Equation 5) (Ref. 1: Eq. 5.6)

P = probability of occurrence.
X = flood magnitude in cfs.
X_{bar} = average flood magnitude from data series in cfs.
σ_x = standard deviation of annual low flows from data series.

c. Log Pearson Type III Frequency Distribution

Adopted by the U.S. Water Resources Council in 1967 as a standard for use by federal agencies, the log Pearson Type III procedure converts the series of USGS gage station data for annual low flow to logarithms and computes the mean, standard deviation, and skew coefficient (*g*).

$$g_{skew} := \frac{N \cdot \Sigma\left(X_{log} - X_{log\_bar}\right)^3}{(N-1)\cdot(N-2)\cdot\left(\sigma_{log\_x}\right)^3}$$ (Equation 6) (Ref. 1: Eq. 5.7)

$$\sigma_{log\_x} := \left(\frac{\Sigma\left(X_{log} - X_{log\_bar}\right)^2}{N - 1}\right)^{\frac{1}{2}}$$ (Equation 7)

N = period of record.
g_{skew} = skew coefficient.
X_{log} = log X.
X_{log_bar} = average "log X" from data series.
σ_{log_x} = standard deviation of "log X" from data series.

To construct the frequency distribution for the two gage stations, values for the frequency factor K were interpolated from Table A-5 (see ***Reference 1***) at various recurrence intervals (2, 10, 25, 50, 100, and 200 years) for the computed value of g. The flow (X) was then estimated for each return period using the following equation:

$$X_{log} := X_{log\_bar} + K \cdot \sigma_{log\_x}$$ (Equation 8)
(Rev. 1: Eq. 5.8)

K = value from Table A-5 (see ***Reference 1***, used linear interpolation based on calculated skew coefficient from data series).

Remember that the probability (P) corresponding to these estimated flows is of a flow of equal or greater magnitude occurring based on the given data series. Therefore, the probability of occurrence of a flow *lower than* the estimated flow (X) can be expressed as 1 – P. This probability is then plotted against flow to develop the low flow frequency distribution. Plots comparing the three (3) calculated frequency distributions, as well as the extrapolation of log Pearson Type III distributions at the Wilkes-Barre and Danville gage stations, can be found in ***Attachment B***. For more information about the log Pearson Type III distribution method, consult ***Reference 1***.

2. Site Low Flow Statistics

Low flow statistics including the 1-day 10-year low flow ($Q_{1,10}$: low stream flow over 1 day which, on a statistical basis, can be expected to occur once every 10 years), 7-day 10-year low flow ($Q_{7,10}$: low stream flow over 7 consecutive days which, on a statistical basis, can be expected to occur once every 10 years), and 30-day 10-year low flow ($Q_{30,10}$: low stream flow over 30 consecutive days which, on a statistical basis, can be expected to occur once every 10 years) were calculated for the Wilkes-Barre and Danville gage stations on the Susquehanna River using USGS daily flow data from water years 1906 through 2006. In addition to determining low flow statistics for the entire period of record (1906 through 2006), data from water years 1906 through 1941 and 1981 through 2006 were also evaluated separately in order to determine the impacts associated with factors such as increased water demand and the regulation of flow by dams. The overall mean, median and harmonic mean were also calculated at each gage station (Wilkes-Barre and Danville) for each period of record evaluated (1906 through 2006, 1906 through 1941, and 1981 through 2006). Upstream and downstream low flow statistics ($Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$) were transferred to the site using drainage area ratios (DA_{site}/DA_{gage}) as suggested by the USGS and PaDEP (see ***Reference 3***). The upstream and downstream gage drainage areas are measured by the USGS as follows: DA_{ug} = 9,960 square miles and DA_{dg} = 11,220 square miles, respectively. The impact point drainage area (DA_{ip}), or site drainage area, is taken as 10,200 square miles (***Reference 2***). All calculated statistics are summarized in ***Table 2***.

Results:

1. Low Flow Frequency Distributions

The extended tables showing all calculations can be found in ***Attachment A***; plots comparing the three (3) calculated frequency distributions, as well as the extrapolation of log Pearson Type III distributions at the Wilkes-Barre and Danville gage stations, can be found in ***Attachment B***. The table below summarizes the recurrence intervals calculated for the lowest on record flow at each gage station.

TABLE 1 – ESTIMATED RECURRENCE INTERVALS

Gage Station	Water Year of Low Flow Event	Flow [cfs]	*Estimated Recurrence Interval*		
			Weilbull T_r [yr]	Gumbel T_r [yr]	Log Pearson Type III T_r* [yr]
Wilkes-Barre	1964	532	109	33	4
Danville	1964	558	102	87	4

*T_r estimated using power trendline with R^2<0.90 at each gage station (see ***Attachment B***).

2. Site Low Flow Statistics

All low flow statistics are summarized in the table below.

TABLE 2 – SUMMARY OF LOW FLOW STATISTICS

Gage Station	Drainage Area [mi^2]	Period of Record	$Q_{1,10}$ [cfs]	$Q_{7,10}$ [cfs]	$Q_{30,10}$ [cfs]	Mean [cfs]	Median [cfs]	Harmonic Mean [cfs]
Wilkes-Barre (upstream)	9,960	1906 - 2006	799	850	1,032	13,606	7,390	4,283
		1906 - 1941	871	908	1,069	12,618	6,540	3,880
		1981 - 2006	779	828	1,098	14,530	8,625	4,933
Danville (downstream)	11,220	1906 - 2006	945	1,017	1,284	15,501	8,770	5,262
		1906 - 1941	969	1,056	1,353	14,769	7,870	4,925
		1981 - 2006	934	1,013	1,345	16,322	10,000	6,030
Site (using upstream gage)	10,200	1906 - 2006	818	870	1,056	-	-	-
		1906 - 1941	891	930	1,095	-	-	-
		1981 - 2006	798	848	1,124	-	-	-
Site (using downstream gage)	10,200	1906 - 2006	859	924	1,167	-	-	-
		1906 - 1941	881	960	1,230	-	-	-
		1981 - 2006	849	921	1,223	-	-	-

Excel worksheets showing the calculations of all low flow statistics, along with the USGS daily flow data that was used for analysis at each gage station, can be found in the following file locations:

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre Daily Flow Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville Daily Flow Data

Conclusions:

The safety of the BBNPP site can be evaluated further now that the recurrence interval and impact associated with various low flow events have been estimated.

Attachment A

Calculated Low Flow Frequency Distributions (Weilbull, Gumbel, and Log Pearson Type III) for Wilkes-Barre and Danville USGS Gage Stations

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

Low Flow Probability Distribution Formulas

The Weilbull, Gumbel, and Log Pearson Type III distribution methods are commonly used to determine the probability of a flood event occurrence. However, the same models can be used for low flow by solving for the probability that the flow is *less than*, as opposed to greater than or equal to, a flow event of a given magnitude (instead of solving for P, solve for 1 - P).

Weilbull Distribution:

$$P := \frac{1}{T_r}$$ (Equation 1) (Ref. 1: Eq. 5.2)

$$T_r := \frac{N+1}{m}$$ (Equation 2) (Ref. 1: Eq. 5.1)

P = probability of occurrence.
N = period of record.
m = *m*th smallest flow in data series.
T_r = recurrence interval.

Gumbel Distribution:

$$P := 1 - \left(1 - e^{-e^{-b}}\right)$$ (Equation 3) (Ref. 1: Eq. 5.4)

$$b := \frac{1}{0.7797 \cdot \sigma_x} \cdot \left(X - X_{bar} + 0.45 \cdot \sigma_x\right)$$ (Equation 4) (Ref. 1: Eq. 5.5)

$$\sigma_x := \left(\frac{\Sigma\left(X - X_{bar}\right)^2}{N-1}\right)^{\frac{1}{2}}$$ (Equation 5) (Ref. 1: Eq. 5.6)

P = probability of occurrence.
X = flood magnitude in cfs.
X_{bar} = average flood magnitude from data series in cfs.
σ_x = standard deviation of annual low flows from data series.

log Pearson Type III Distribution:

$$g_{skew} := \frac{N \cdot \Sigma\left(X_{log} - X_{log\_bar}\right)^3}{(N-1)\cdot(N-2)\cdot\left(\sigma_{log\_x}\right)^3}$$ (Equation 6) (Ref. 1: Eq. 5.7)

$$\sigma_{log\_x} := \left(\frac{\Sigma\left(X_{log} - X_{log\_bar}\right)^2}{N-1}\right)^{\frac{1}{2}}$$ (Equation 7)

N = period of record.
g_{skew} = skew coefficient.
X_{log} = log X.
X_{log_bar} = average "log X" from data series.
σ_{log_x} = standard deviation of "log X" from data series.

$$X_{log} := X_{log\_bar} + K \cdot \sigma_{log\_x}$$ (Equation 8) (Ref. 1: Eq. 5.8)

K = value from Table A-5 in text (see ***Reference 1***, used linear interpolation based on calculated skew coefficient from data series).

Developing the Log Pearson Type III Distribution for the low flow scenario follows the same approach as for peak flow: calculate the skew coefficient based on the available gage station flow data, and using that value interpolate the corresponding frequency factor (K) at various recurrence intervals to develop a frequency distribution which can be used to estimate flow. Since the formulas and tables above that are used to develop this distribution were created to determine the probability of peak flow events (probability of occurrence / recurrence interval of a flow of equal or greater magnitude), the probability of the estimated flow that is of interest for low flow analysis is instead the probability that a flow of lower magnitude occurs. Therefore, the distribution is created by plotting the estimated flow against the recurrence interval, which is calculated using 1 - P for probability as opposed to P.

*Text Reference: "Water-Resources Engineering," McGraw-Hill, Fourth Edition. (Chapter 5: Probability Concepts in Planning)

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By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Sheet No. A4 of A25
Chkd.By FAm Date 09-18-09 Project No. 07-3891

Low Flow Frequency Distributions (Weilbull and Gumbel) for Wilkes-Barre Gage Station

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	X - X_{bar}	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
1	0.53	532	1964	109.0	0.0092	-888	788,051	-1.25	0.0302	33
2	0.63	625	1939	54.5	0.0183	-795	631,583	-1.06	0.0557	18
3	0.66	658	1941	36.3	0.0275	-762	580,221	-0.99	0.0673	15
4	0.69	686	1962	27.3	0.0367	-734	538,348	-0.93	0.0783	13
5	0.70	700	1963	21.8	0.0459	-720	518,000	-0.91	0.0842	12
6	0.72	720	1900	18.2	0.0550	-700	489,611	-0.86	0.0930	11
7	0.72	720	1955	15.6	0.0642	-700	489,611	-0.86	0.0930	11
8	0.75	749	1999	13.6	0.0734	-671	449,868	-0.81	0.1068	9
9	0.76	760	1908	12.1	0.0826	-660	435,233	-0.78	0.1123	9
10	0.78	779	1959	10.9	0.0917	-641	410,525	-0.74	0.1221	8
11	0.78	780	1953	9.9	0.1009	-640	409,245	-0.74	0.1226	8
12	0.80	795	1991	9.1	0.1101	-625	390,278	-0.71	0.1307	8
13	0.81	810	1911	8.4	0.1193	-610	371,761	-0.68	0.1391	7
14	0.82	815	1965	7.8	0.1284	-605	365,689	-0.67	0.1419	7
15	0.82	820	1899	7.3	0.1376	-600	359,667	-0.66	0.1448	7
16	0.82	820	1913	6.8	0.1468	-600	359,667	-0.66	0.1448	7
17	0.83	831	1995	6.4	0.1560	-589	346,594	-0.64	0.1512	7
18	0.86	860	1910	6.1	0.1651	-560	313,289	-0.58	0.1687	6
19	0.87	871	1966	5.7	0.1743	-549	301,096	-0.55	0.1756	6
20	0.89	887	1985	5.5	0.1835	-533	283,793	-0.52	0.1858	5
21	0.89	892	1954	5.2	0.1927	-528	278,491	-0.51	0.1890	5
22	0.89	893	1912	5.0	0.2018	-527	277,436	-0.51	0.1896	5
23	0.92	924	2002	4.7	0.2110	-496	245,741	-0.44	0.2102	5
24	0.93	932	1932	4.5	0.2202	-488	237,873	-0.43	0.2156	5
25	0.95	951	1918	4.4	0.2294	-469	219,701	-0.39	0.2287	4
26	0.97	970	1907	4.2	0.2385	-450	202,250	-0.35	0.2420	4
27	0.97	970	1909	4.0	0.2477	-450	202,250	-0.35	0.2420	4
28	0.97	970	1930	3.9	0.2569	-450	202,250	-0.35	0.2420	4
29	0.98	980	1983	3.8	0.2661	-440	193,356	-0.33	0.2492	4
30	1.00	1,000	1929	3.6	0.2752	-420	176,167	-0.29	0.2635	4
31	1.01	1,010	1943	3.5	0.2844	-410	167,872	-0.27	0.2708	4
32	1.01	1,010	1949	3.4	0.2936	-410	167,872	-0.27	0.2708	4
33	1.02	1,020	1980	3.3	0.3028	-400	159,778	-0.25	0.2781	4
34	1.05	1,050	1906	3.2	0.3119	-370	136,695	-0.18	0.3003	3
35	1.05	1,050	1982	3.1	0.3211	-370	136,695	-0.18	0.3003	3
36	1.05	1,050	2005	3.0	0.3303	-370	136,695	-0.18	0.3003	3
37	1.06	1,060	1917	2.9	0.3394	-360	129,400	-0.16	0.3078	3

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

PAUL C. RIZZO ASSOCIATES, INC.
CONSULTANTS

By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Sheet No. A5 of A25
Chkd.By FAM Date 09-18-09 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
38	1.06	1,060	1923	2.9	0.3486	-360	129,400	-0.16	0.3078	3
39	1.06	1,060	1948	2.8	0.3578	-360	129,400	-0.16	0.3078	3
40	1.06	1,060	1957	2.7	0.3670	-360	129,400	-0.16	0.3078	3
41	1.06	1,060	1988	2.7	0.3761	-360	129,400	-0.16	0.3078	3
42	1.08	1,080	1931	2.6	0.3853	-340	115,411	-0.12	0.3228	3
43	1.09	1,090	1969	2.5	0.3945	-330	108,717	-0.10	0.3303	3
44	1.10	1,100	2001	2.5	0.4037	-320	102,222	-0.08	0.3378	3
45	1.15	1,150	1936	2.4	0.4128	-270	72,750	0.02	0.3757	3
46	1.15	1,150	1944	2.4	0.4220	-270	72,750	0.02	0.3757	3
47	1.16	1,160	1916	2.3	0.4312	-260	67,456	0.04	0.3833	3
48	1.19	1,190	1989	2.3	0.4404	-230	52,772	0.10	0.4060	2
49	1.20	1,200	1934	2.2	0.4495	-220	48,278	0.12	0.4135	2
50	1.21	1,210	1993	2.2	0.4587	-210	43,983	0.14	0.4210	2
51	1.25	1,250	1914	2.1	0.4679	-170	28,806	0.23	0.4508	2
52	1.26	1,260	1987	2.1	0.4771	-160	25,511	0.25	0.4582	2
53	1.28	1,280	1961	2.1	0.4862	-140	19,522	0.29	0.4729	2
54	1.28	1,280	1981	2.0	0.4954	-140	19,522	0.29	0.4729	2
55	1.32	1,320	1952	2.0	0.5046	-100	9,945	0.37	0.5018	2
56	1.33	1,330	1921	1.9	0.5138	-90	8,050	0.39	0.5089	2
57	1.33	1,330	1970	1.9	0.5229	-90	8,050	0.39	0.5089	2
58	1.34	1,340	1933	1.9	0.5321	-80	6,356	0.41	0.5159	2
59	1.35	1,350	1928	1.8	0.5413	-70	4,861	0.43	0.5230	2
60	1.38	1,380	1926	1.8	0.5505	-40	1,578	0.50	0.5437	2
61	1.39	1,390	1951	1.8	0.5596	-30	883	0.52	0.5505	2
62	1.44	1,440	1960	1.8	0.5688	20	411	0.62	0.5836	2
63	1.44	1,440	1997	1.7	0.5780	20	411	0.62	0.5836	2
64	1.45	1,450	1971	1.7	0.5872	30	917	0.64	0.5901	2
65	1.46	1,460	1940	1.7	0.5963	40	1,622	0.66	0.5964	2
66	1.47	1,470	1979	1.7	0.6055	50	2,528	0.68	0.6028	2
67	1.49	1,490	1915	1.6	0.6147	70	4,939	0.72	0.6152	2
68	1.50	1,500	1919	1.6	0.6239	80	6,445	0.74	0.6213	2
69	1.50	1,500	1947	1.6	0.6330	80	6,445	0.74	0.6213	2
70	1.50	1,500	1972	1.6	0.6422	80	6,445	0.74	0.6213	2
71	1.50	1,500	1998	1.5	0.6514	80	6,445	0.74	0.6213	2
72	1.51	1,510	1968	1.5	0.6606	90	8,150	0.76	0.6274	2
73	1.52	1,520	1978	1.5	0.6697	100	10,056	0.78	0.6334	2
74	1.57	1,570	1984	1.5	0.6789	150	22,583	0.89	0.6624	2
75	1.58	1,580	1938	1.5	0.6881	160	25,689	0.91	0.6679	1
76	1.60	1,600	1927	1.4	0.6972	180	32,500	0.95	0.6789	1
77	1.61	1,610	1922	1.4	0.7064	190	36,206	0.97	0.6843	1

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By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Sheet No. A6 of A25
Chkd.By FAM Date 09-18-09 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
78	1.66	1,660	1935	1.4	0.7156	240	57,733	1.07	0.7102	1
79	1.66	1,660	1974	1.4	0.7248	240	57,733	1.07	0.7102	1
80	1.67	1,670	1924	1.4	0.7339	250	62,639	1.09	0.7152	1
81	1.70	1,700	1958	1.3	0.7431	280	78,556	1.15	0.7297	1
82	1.74	1,740	1925	1.3	0.7523	320	102,578	1.24	0.7481	1
83	1.76	1,760	1956	1.3	0.7615	340	115,789	1.28	0.7569	1
84	1.76	1,760	1986	1.3	0.7706	340	115,789	1.28	0.7569	1
85	1.81	1,810	1901	1.3	0.7798	390	152,317	1.38	0.7779	1
86	1.81	1,810	1903	1.3	0.7890	390	152,317	1.38	0.7779	1
87	1.84	1,840	1973	1.3	0.7982	420	176,633	1.44	0.7897	1
88	1.85	1,850	1946	1.2	0.8073	430	185,139	1.46	0.7935	1
89	1.85	1,850	1950	1.2	0.8165	430	185,139	1.46	0.7935	1
90	1.85	1,850	1977	1.2	0.8257	430	185,139	1.46	0.7935	1
91	1.88	1,880	1937	1.2	0.8349	460	211,856	1.53	0.8046	1
92	1.90	1,900	1975	1.2	0.8440	480	230,667	1.57	0.8117	1
93	1.95	1,950	1996	1.2	0.8532	530	281,195	1.67	0.8284	1
94	2.00	2,000	1902	1.2	0.8624	580	336,722	1.77	0.8438	1
95	2.20	2,200	1904	1.1	0.8716	780	608,833	2.19	0.8936	1
96	2.26	2,260	1942	1.1	0.8807	840	706,067	2.31	0.9054	1
97	2.26	2,260	1990	1.1	0.8899	840	706,067	2.31	0.9054	1
98	2.28	2,280	2000	1.1	0.8991	860	740,078	2.35	0.9090	1
99	2.29	2,290	1920	1.1	0.9083	870	757,383	2.37	0.9108	1
100	2.29	2,290	1992	1.1	0.9174	870	757,383	2.37	0.9108	1
101	2.50	2,500	1967	1.1	0.9266	1,080	1,167,000	2.80	0.9412	1
102	2.62	2,620	1905	1.1	0.9358	1,200	1,440,667	3.05	0.9538	1
103	2.71	2,710	1945	1.1	0.9450	1,290	1,664,817	3.24	0.9615	1
104	2.83	2,830	2004	1.0	0.9541	1,410	1,988,883	3.48	0.9698	1
105	2.90	2,900	1994	1.0	0.9633	1,480	2,191,222	3.63	0.9738	1
106	3.15	3,150	2006	1.0	0.9725	1,730	2,993,861	4.14	0.9843	1
107	3.58	3,580	2003	1.0	0.9817	2,160	4,666,800	5.03	0.9935	1
108	3.60	3,600	1976	1.0	0.9908	2,180	4,753,611	5.07	0.9937	1
Avg.=	X_{bar}=	1,420	-	-	-	-	-	-	-	-
Sum=	-	153,330	-	-	-	0	41,440,078	-	-	-

σ_x = 622.3

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

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By __DW__ Date _7/22/2009_ Subject ___Low Flow Recurrence Interval and___ Sheet No. _A7_ of _A25_
Chkd.By _FAM_ Date _09-18-09_ ___Low Flow Statistics (BBNPP) (Rev. 2)___ Project No. _07-3891_

Low Flow Frequency Distribution (log Pearson Type III) for Wilkes-Barre Gage Station

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)^2	(log X - (log X)bar)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r(yr)	K	Estimated Flow (X), cfs
1	0.53	532	1964	2.726	-0.390	0.152	-0.0592	0.3031	2	0.5	0.5	2.0000	-0.0505	1,279
2	0.63	625	1939	2.796	-0.320	0.102	-0.0327	-	10	0.1	0.9	1.1111	1.3092	2,218
3	0.66	658	1941	2.818	-0.297	0.089	-0.0263	-	25	0.04	0.96	1.0417	1.8500	2,761
4	0.69	686	1962	2.836	-0.279	0.078	-0.0218	-	50	0.02	0.98	1.0204	2.2126	3,197
5	0.70	700	1963	2.845	-0.271	0.073	-0.0198	-	100	0.01	0.99	1.0101	2.5462	3,660
6	0.72	720	1900	2.857	-0.258	0.067	-0.0173	-	200	0.005	0.995	1.0050	2.8589	4,154
7	0.72	720	1955	2.857	-0.258	0.067	-0.0173	-	-	-	-	-	-	-
8	0.75	749	1999	2.874	-0.241	0.058	-0.0140	-	-	-	-	-	-	-
9	0.76	760	1908	2.881	-0.235	0.055	-0.0130	-	-	-	-	-	-	-
10	0.78	779	1959	2.892	-0.224	0.050	-0.0113	-	-	-	-	-	-	-
11	0.78	780	1953	2.892	-0.224	0.050	-0.0112	-	-	-	-	-	-	-
12	0.80	795	1991	2.900	-0.215	0.046	-0.0100	-	-	-	-	-	-	-
13	0.81	810	1911	2.908	-0.207	0.043	-0.0089	-	-	-	-	-	-	-
14	0.82	815	1965	2.911	-0.205	0.042	-0.0086	-	-	-	-	-	-	-
15	0.82	820	1899	2.914	-0.202	0.041	-0.0082	-	-	-	-	-	-	-

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution											
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)^2	(log X - (log X)bar)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r(yr)	K	Estimated Flow (X), cfs
16	0.82	820	1913	2.914	-0.202	0.041	-0.0082	-	-	-	-	-	-	-
17	0.83	831	1995	2.920	-0.196	0.038	-0.0075	-	-	-	-	-	-	-
18	0.86	860	1910	2.934	-0.181	0.033	-0.0060	-	-	-	-	-	-	-
19	0.87	871	1966	2.940	-0.176	0.031	-0.0054	-	-	-	-	-	-	-
20	0.89	887	1985	2.948	-0.168	0.028	-0.0047	-	-	-	-	-	-	-
21	0.89	892	1954	2.950	-0.165	0.027	-0.0045	-	-	-	-	-	-	-
22	0.89	893	1912	2.951	-0.165	0.027	-0.0045	-	-	-	-	-	-	-
23	0.92	924	2002	2.966	-0.150	0.023	-0.0034	-	-	-	-	-	-	-
24	0.93	932	1932	2.969	-0.146	0.021	-0.0031	-	-	-	-	-	-	-
25	0.95	951	1918	2.978	-0.138	0.019	-0.0026	-	-	-	-	-	-	-
26	0.97	970	1907	2.987	-0.129	0.017	-0.0021	-	-	-	-	-	-	-
27	0.97	970	1909	2.987	-0.129	0.017	-0.0021	-	-	-	-	-	-	-
28	0.97	970	1930	2.987	-0.129	0.017	-0.0021	-	-	-	-	-	-	-
29	0.98	980	1983	2.991	-0.124	0.016	-0.0019	-	-	-	-	-	-	-
30	1.00	1,000	1929	3.000	-0.116	0.013	-0.0015	-	-	-	-	-	-	-
31	1.01	1,010	1943	3.004	-0.111	0.012	-0.0014	-	-	-	-	-	-	-

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)^2	(log X - (log X)bar)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
32	1.01	1,010	1949	3.004	-0.111	0.012	-0.0014	-	-	-	-	-	-	-
33	1.02	1,020	1980	3.009	-0.107	0.011	-0.0012	-	-	-	-	-	-	-
34	1.05	1,050	1906	3.021	-0.095	0.009	-0.0008	-	-	-	-	-	-	-
35	1.05	1,050	1982	3.021	-0.095	0.009	-0.0008	-	-	-	-	-	-	-
36	1.05	1,050	2005	3.021	-0.095	0.009	-0.0008	-	-	-	-	-	-	-
37	1.06	1,060	1917	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
38	1.06	1,060	1923	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
39	1.06	1,060	1948	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
40	1.06	1,060	1957	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
41	1.06	1,060	1988	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
42	1.08	1,080	1931	3.033	-0.082	0.007	-0.0006	-	-	-	-	-	-	-
43	1.09	1,090	1969	3.037	-0.078	0.006	-0.0005	-	-	-	-	-	-	-
44	1.10	1,100	2001	3.041	-0.074	0.006	-0.0004	-	-	-	-	-	-	-
45	1.15	1,150	1936	3.061	-0.055	0.003	-0.0002	-	-	-	-	-	-	-
46	1.15	1,150	1944	3.061	-0.055	0.003	-0.0002	-	-	-	-	-	-	-
47	1.16	1,160	1916	3.064	-0.051	0.003	-0.0001	-	-	-	-	-	-	-
48	1.19	1,190	1989	3.076	-0.040	0.002	-0.0001	-	-	-	-	-	-	-

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution											
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
49	1.20	1,200	1934	3.079	-0.037	0.001	0.0000	-	-	-	-	-	-	-
50	1.21	1,210	1993	3.083	-0.033	0.001	0.0000	-	-	-	-	-	-	-
51	1.25	1,250	1914	3.097	-0.019	0.000	0.0000	-	-	-	-	-	-	-
52	1.26	1,260	1987	3.100	-0.015	0.000	0.0000	-	-	-	-	-	-	-
53	1.28	1,280	1961	3.107	-0.009	0.000	0.0000	-	-	-	-	-	-	-
54	1.28	1,280	1981	3.107	-0.009	0.000	0.0000	-	-	-	-	-	-	-
55	1.32	1,320	1952	3.121	0.005	0.000	0.0000	-	-	-	-	-	-	-
56	1.33	1,330	1921	3.124	0.008	0.000	0.0000	-	-	-	-	-	-	-
57	1.33	1,330	1970	3.124	0.008	0.000	0.0000	-	-	-	-	-	-	-
58	1.34	1,340	1933	3.127	0.011	0.000	0.0000	-	-	-	-	-	-	-
59	1.35	1,350	1928	3.130	0.015	0.000	0.0000	-	-	-	-	-	-	-
60	1.38	1,380	1926	3.140	0.024	0.001	0.0000	-	-	-	-	-	-	-
61	1.39	1,390	1951	3.143	0.027	0.001	0.0000	-	-	-	-	-	-	-
62	1.44	1,440	1960	3.158	0.043	0.002	0.0001	-	-	-	-	-	-	-
63	1.44	1,440	1997	3.158	0.043	0.002	0.0001	-	-	-	-	-	-	-
64	1.45	1,450	1971	3.161	0.046	0.002	0.0001	-	-	-	-	-	-	-
65	1.46	1,460	1940	3.164	0.049	0.002	0.0001	-	-	-	-	-	-	-

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By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Sheet No. A11 of A25
Chkd.By fmm Date 09-18-09 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution											
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r(yr)	K	Estimated Flow (X), cfs
66	1.47	1,470	1979	3.167	0.052	0.003	0.0001	-	-	-	-	-	-	-
67	1.49	1,490	1915	3.173	0.057	0.003	0.0002	-	-	-	-	-	-	-
68	1.50	1,500	1919	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
69	1.50	1,500	1947	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
70	1.50	1,500	1972	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
71	1.50	1,500	1998	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
72	1.51	1,510	1968	3.179	0.063	0.004	0.0003	-	-	-	-	-	-	-
73	1.52	1,520	1978	3.182	0.066	0.004	0.0003	-	-	-	-	-	-	-
74	1.57	1,570	1984	3.196	0.080	0.006	0.0005	-	-	-	-	-	-	-
75	1.58	1,580	1938	3.199	0.083	0.007	0.0006	-	-	-	-	-	-	-
76	1.60	1,600	1927	3.204	0.088	0.008	0.0007	-	-	-	-	-	-	-
77	1.61	1,610	1922	3.207	0.091	0.008	0.0008	-	-	-	-	-	-	-
78	1.66	1,660	1935	3.220	0.104	0.011	0.0011	-	-	-	-	-	-	-
79	1.66	1,660	1974	3.220	0.104	0.011	0.0011	-	-	-	-	-	-	-
80	1.67	1,670	1924	3.223	0.107	0.011	0.0012	-	-	-	-	-	-	-
81	1.70	1,700	1958	3.230	0.115	0.013	0.0015	-	-	-	-	-	-	-
82	1.74	1,740	1925	3.241	0.125	0.016	0.0019	-	-	-	-	-	-	-

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

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By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Sheet No. A12 of A25
Chkd.By fmn Date 09-18-09 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution											
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
83	1.76	1,760	1956	3.246	0.130	0.017	0.0022	-	-	-	-	-	-	-
84	1.76	1,760	1986	3.246	0.130	0.017	0.0022	-	-	-	-	-	-	-
85	1.81	1,810	1901	3.258	0.142	0.020	0.0029	-	-	-	-	-	-	-
86	1.81	1,810	1903	3.258	0.142	0.020	0.0029	-	-	-	-	-	-	-
87	1.84	1,840	1973	3.265	0.149	0.022	0.0033	-	-	-	-	-	-	-
88	1.85	1,850	1946	3.267	0.151	0.023	0.0035	-	-	-	-	-	-	-
89	1.85	1,850	1950	3.267	0.151	0.023	0.0035	-	-	-	-	-	-	-
90	1.85	1,850	1977	3.267	0.151	0.023	0.0035	-	-	-	-	-	-	-
91	1.88	1,880	1937	3.274	0.158	0.025	0.0040	-	-	-	-	-	-	-
92	1.90	1,900	1975	3.279	0.163	0.027	0.0043	-	-	-	-	-	-	-
93	1.95	1,950	1996	3.290	0.174	0.030	0.0053	-	-	-	-	-	-	-
94	2.00	2,000	1902	3.301	0.185	0.034	0.0064	-	-	-	-	-	-	-
95	2.20	2,200	1904	3.342	0.227	0.051	0.0117	-	-	-	-	-	-	-
96	2.26	2,260	1942	3.354	0.238	0.057	0.0135	-	-	-	-	-	-	-
97	2.26	2,260	1990	3.354	0.238	0.057	0.0135	-	-	-	-	-	-	-
98	2.28	2,280	2000	3.358	0.242	0.059	0.0142	-	-	-	-	-	-	-
99	2.29	2,290	1920	3.360	0.244	0.060	0.0145	-	-	-	-	-	-	-

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution											
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)²	(log X - (log X)bar)³	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
100	2.29	2,290	1992	3.360	0.244	0.060	0.0145	-	-	-	-	-	-	-
101	2.50	2,500	1967	3.398	0.282	0.080	0.0225	-	-	-	-	-	-	-
102	2.62	2,620	1905	3.418	0.303	0.092	0.0277	-	-	-	-	-	-	-
103	2.71	2,710	1945	3.433	0.317	0.101	0.0319	-	-	-	-	-	-	-
104	2.83	2,830	2004	3.452	0.336	0.113	0.0380	-	-	-	-	-	-	-
105	2.90	2,900	1994	3.462	0.347	0.120	0.0417	-	-	-	-	-	-	-
106	3.15	3,150	2006	3.498	0.383	0.146	0.0560	-	-	-	-	-	-	-
107	3.58	3,580	2003	3.554	0.438	0.192	0.0841	-	-	-	-	-	-	-
108	3.60	3,600	1976	3.556	0.441	0.194	0.0855	-	-	-	-	-	-	-
Avg.=	X_{bar}=	1,420	$(logX)_{bar}$=	3.116	-	-	-	-	-	-	-	-	-	-
Sum=	-	153,330	-	336.498	-	3.308	0.1731	-	-	-	-	-	-	-

$\sigma_{log\,x}$ = 0.176

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G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

Low Flow Probability Distribution Formulas

The Weilbull, Gumbel, and Log Pearson Type III distribution methods are commonly used to determine the probability of a flood event occurrence. However, the same models can be used for low flow by solving for the probability that the flow is *less than*, as opposed to greater than or equal to, a flow event of a given magnitude (instead of solving for P, solve for 1 - P).

Weilbull Distribution:

$$P := \frac{1}{T_r}$$ (Equation 1) (Ref. 1: Eq. 5.2)

$$T_r := \frac{N+1}{m}$$ (Equation 2) (Ref. 1: Eq. 5.1)

P = probability of occurrence.
N = period of record.
m = *m*th smallest flow in data series.
T_r = recurrence interval.

Gumbel Distribution:

$$P := 1 - \left(1 - e^{-e^{-b}}\right)$$ (Equation 3) (Ref. 1: Eq. 5.4)

$$b := \frac{1}{0.7797 \cdot \sigma_x} \cdot \left(X - X_{bar} + 0.45 \cdot \sigma_x\right)$$ (Equation 4) (Ref. 1: Eq. 5.5)

$$\sigma_x := \left(\frac{\Sigma\left(X - X_{bar}\right)^2}{N-1}\right)^{\frac{1}{2}}$$ (Equation 5) (Ref. 1: Eq. 5.6)

P = probability of occurrence.
X = flood magnitude in cfs.
X_{bar} = average flood magnitude from data series in cfs.
σ_x = standard deviation of annual low flows from data series.

log Pearson Type III Distribution:

$$g_{skew} := \frac{N \cdot \Sigma\left(X_{log} - X_{log\_bar}\right)^3}{(N-1)\cdot(N-2)\cdot\left(\sigma_{log\_x}\right)^3}$$ (Equation 6) (Ref. 1: Eq. 5.7)

$$\sigma_{log\_x} := \left(\frac{\Sigma\left(X_{log} - X_{log\_bar}\right)^2}{N-1}\right)^{\frac{1}{2}}$$ (Equation 7)

N = period of record.
g_{skew} = skew coefficient.
X_{log} = log X.
X_{log_bar} = average "log X" from data series.
σ_{log_x} = standard deviation of "log X" from data series.

$$X_{log} := X_{log\_bar} + K \cdot \sigma_{log\_x}$$ (Equation 8) (Ref. 1: Eq. 5.8)

K = value from Table A-5 in text (see ***Reference 1***, used linear interpolation based on calculated skew coefficient from data series).

Developing the Log Pearson Type III Distribution for the low flow scenario follows the same approach as for peak flow: calculate the skew coefficient based on the available gage station flow data, and using that value interpolate the corresponding frequency factor (K) at various recurrence intervals to develop a frequency distribution which can be used to estimate flow. Since the formulas and tables above that are used to develop this distribution were created to determine the probability of peak flow events (probability of occurrence / recurrence interval of a flow of equal or greater magnitude), the probability of the estimated flow that is of interest for low flow analysis is instead the probability that a flow of lower magnitude occurs. Therefore, the distribution is created by plotting the estimated flow against the recurrence interval, which is calculated using 1 - P for probability as opposed to P.

*Text Reference: "Water-Resources Engineering," McGraw-Hill, Fourth Edition. (Chapter 5: Probability Concepts in Planning)

Low Flow Frequency Distributions (Weilbull and Gumbel) for Danville Gage Station

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
1	0.56	558	1964	102.0	0.0098	-1,160	1,346,588	-1.50	0.0116	87
2	0.72	722	1939	51.0	0.0196	-996	992,864	-1.20	0.0359	28
3	0.84	839	1963	34.0	0.0294	-879	773,390	-0.99	0.0672	15
4	0.84	840	1999	25.5	0.0392	-878	771,632	-0.99	0.0675	15
5	0.86	855	1908	20.4	0.0490	-863	745,504	-0.96	0.0725	14
6	0.88	876	1955	17.0	0.0588	-842	709,681	-0.93	0.0798	13
7	0.89	888	1962	14.6	0.0686	-830	689,607	-0.91	0.0842	12
8	0.90	900	1965	12.8	0.0784	-818	669,821	-0.88	0.0888	11
9	0.92	918	1959	11.3	0.0882	-800	640,681	-0.85	0.0958	10
10	0.92	920	1913	10.2	0.0980	-798	637,484	-0.85	0.0966	10
11	0.92	920	1930	9.3	0.1078	-798	637,484	-0.85	0.0966	10
12	0.92	920	1932	8.5	0.1176	-798	637,484	-0.85	0.0966	10
13	0.95	952	1941	7.8	0.1275	-766	587,408	-0.79	0.1100	9
14	0.98	982	1991	7.3	0.1373	-736	542,323	-0.74	0.1235	8
15	0.99	991	1953	6.8	0.1471	-727	529,148	-0.72	0.1276	8
16	1.02	1,020	1936	6.4	0.1569	-698	487,799	-0.67	0.1416	7
17	1.06	1,060	1966	6.0	0.1667	-658	433,524	-0.60	0.1620	6
18	1.09	1,090	2002	5.7	0.1765	-628	394,919	-0.55	0.1782	6
19	1.10	1,100	1910	5.4	0.1863	-618	382,450	-0.53	0.1837	5
20	1.11	1,110	1954	5.1	0.1961	-608	370,182	-0.51	0.1893	5
21	1.12	1,120	1909	4.9	0.2059	-598	358,113	-0.49	0.1950	5
22	1.15	1,150	1949	4.6	0.2157	-568	323,108	-0.44	0.2123	5
23	1.21	1,210	1911	4.4	0.2255	-508	258,497	-0.33	0.2485	4
24	1.21	1,210	1948	4.3	0.2353	-508	258,497	-0.33	0.2485	4
25	1.22	1,220	1923	4.1	0.2451	-498	248,428	-0.31	0.2547	4
26	1.22	1,220	1931	3.9	0.2549	-498	248,428	-0.31	0.2547	4
27	1.24	1,240	1907	3.8	0.2647	-478	228,891	-0.28	0.2673	4
28	1.24	1,240	1980	3.6	0.2745	-478	228,891	-0.28	0.2673	4
29	1.25	1,250	1943	3.5	0.2843	-468	219,423	-0.26	0.2736	4
30	1.27	1,270	1944	3.4	0.2941	-448	201,086	-0.22	0.2863	3
31	1.28	1,280	2005	3.3	0.3039	-438	192,217	-0.21	0.2927	3
32	1.29	1,290	1952	3.2	0.3137	-428	183,549	-0.19	0.2991	3
33	1.30	1,300	1983	3.1	0.3235	-418	175,080	-0.17	0.3056	3
34	1.31	1,310	1934	3.0	0.3333	-408	166,812	-0.15	0.3121	3
35	1.31	1,310	1957	2.9	0.3431	-408	166,812	-0.15	0.3121	3

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weibull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weibull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
36	1.31	1,310	1961	2.8	0.3529	-408	166,812	-0.15	0.3121	3
37	1.40	1,400	1929	2.8	0.3627	-318	101,395	0.01	0.3710	3
38	1.42	1,420	1997	2.7	0.3725	-298	89,058	0.04	0.3841	3
39	1.43	1,430	1982	2.6	0.3824	-288	83,189	0.06	0.3907	3
40	1.45	1,450	1969	2.6	0.3922	-268	72,052	0.10	0.4038	2
41	1.45	1,450	1988	2.5	0.4020	-268	72,052	0.10	0.4038	2
42	1.47	1,470	1940	2.4	0.4118	-248	61,715	0.13	0.4168	2
43	1.48	1,480	1995	2.4	0.4216	-238	56,847	0.15	0.4233	2
44	1.51	1,510	1993	2.3	0.4314	-208	43,441	0.20	0.4428	2
45	1.54	1,540	1971	2.3	0.4412	-178	31,836	0.26	0.4620	2
46	1.57	1,570	1985	2.2	0.4510	-148	22,030	0.31	0.4810	2
47	1.58	1,580	1970	2.2	0.4608	-138	19,162	0.33	0.4873	2
48	1.60	1,600	1912	2.1	0.4706	-118	14,025	0.37	0.4997	2
49	1.61	1,610	1987	2.1	0.4804	-108	11,756	0.38	0.5059	2
50	1.63	1,630	1947	2.0	0.4902	-88	7,819	0.42	0.5181	2
51	1.64	1,640	1906	2.0	0.5000	-78	6,151	0.44	0.5242	2
52	1.64	1,640	1951	2.0	0.5098	-78	6,151	0.44	0.5242	2
53	1.66	1,660	1989	1.9	0.5196	-58	3,414	0.47	0.5362	2
54	1.68	1,680	2001	1.9	0.5294	-38	1,477	0.51	0.5481	2
55	1.70	1,700	1914	1.9	0.5392	-18	340	0.54	0.5597	2
56	1.70	1,700	1915	1.8	0.5490	-18	340	0.54	0.5597	2
57	1.70	1,700	1918	1.8	0.5588	-18	340	0.54	0.5597	2
58	1.70	1,700	1998	1.8	0.5686	-18	340	0.54	0.5597	2
59	1.71	1,710	1968	1.7	0.5784	-8	71	0.56	0.5655	2
60	1.71	1,710	1981	1.7	0.5882	-8	71	0.56	0.5655	2
61	1.72	1,720	1938	1.7	0.5980	2	2	0.58	0.5713	2
62	1.73	1,730	1933	1.6	0.6078	12	134	0.60	0.5769	2
63	1.73	1,730	1935	1.6	0.6176	12	134	0.60	0.5769	2
64	1.80	1,800	1922	1.6	0.6275	82	6,654	0.72	0.6155	2
65	1.81	1,810	1919	1.6	0.6373	92	8,386	0.74	0.6208	2
66	1.81	1,810	1921	1.5	0.6471	92	8,386	0.74	0.6208	2
67	1.81	1,810	1926	1.5	0.6569	92	8,386	0.74	0.6208	2
68	1.90	1,900	1979	1.5	0.6667	182	32,969	0.90	0.6663	2
69	1.92	1,920	1928	1.5	0.6765	202	40,632	0.94	0.6759	1
70	1.96	1,960	1937	1.5	0.6863	242	58,358	1.01	0.6944	1
71	1.96	1,960	1974	1.4	0.6961	242	58,358	1.01	0.6944	1
72	1.97	1,970	1984	1.4	0.7059	252	63,290	1.03	0.6989	1
73	1.99	1,990	1972	1.4	0.7157	272	73,753	1.06	0.7077	1
74	2.00	2,000	1920	1.4	0.7255	282	79,284	1.08	0.7121	1
75	2.03	2,030	1927	1.4	0.7353	312	97,079	1.13	0.7248	1

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weibull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weibull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
76	2.04	2,040	1946	1.3	0.7451	322	103,410	1.15	0.7289	1
77	2.06	2,060	1916	1.3	0.7549	342	116,673	1.19	0.7371	1
78	2.10	2,100	1960	1.3	0.7647	382	145,599	1.26	0.7527	1
79	2.11	2,110	1978	1.3	0.7745	392	153,330	1.28	0.7565	1
80	2.14	2,140	1956	1.3	0.7843	422	177,725	1.33	0.7676	1
81	2.15	2,150	1917	1.3	0.7941	432	186,256	1.35	0.7712	1
82	2.15	2,150	1925	1.2	0.8039	432	186,256	1.35	0.7712	1
83	2.15	2,150	1950	1.2	0.8137	432	186,256	1.35	0.7712	1
84	2.16	2,160	1977	1.2	0.8235	442	194,988	1.37	0.7748	1
85	2.20	2,200	1958	1.2	0.8333	482	231,914	1.44	0.7885	1
86	2.20	2,200	1986	1.2	0.8431	482	231,914	1.44	0.7885	1
87	2.27	2,270	1924	1.2	0.8529	552	304,234	1.56	0.8109	1
88	2.30	2,300	1973	1.2	0.8627	582	338,229	1.62	0.8198	1
89	2.38	2,380	1942	1.1	0.8725	662	437,680	1.76	0.8417	1
90	2.49	2,490	1975	1.1	0.8824	772	595,327	1.96	0.8680	1
91	2.64	2,640	1996	1.1	0.8922	922	849,299	2.22	0.8974	1
92	2.70	2,700	1967	1.1	0.9020	982	963,488	2.33	0.9073	1
93	2.83	2,830	2000	1.1	0.9118	1,112	1,235,597	2.56	0.9258	1
94	2.87	2,870	1992	1.1	0.9216	1,152	1,326,123	2.63	0.9307	1
95	3.09	3,090	1990	1.1	0.9314	1,372	1,881,216	3.03	0.9527	1
96	3.22	3,220	1945	1.1	0.9412	1,502	2,254,725	3.26	0.9623	1
97	3.35	3,350	2004	1.1	0.9510	1,632	2,662,035	3.49	0.9700	1
98	3.37	3,370	1994	1.0	0.9608	1,652	2,727,698	3.53	0.9710	1
99	3.64	3,640	2006	1.0	0.9706	1,922	3,692,448	4.01	0.9820	1
100	4.10	4,100	1976	1.0	0.9804	2,382	5,671,896	4.83	0.9920	1
101	4.34	4,340	2003	1.0	0.9902	2,622	6,872,652	5.26	0.9948	1
102	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-
Avg.=	X_{bar}=	1,718	-	-	-	-	-	-	-	-
Sum=	-	173,561	-	-	-	0	51,572,457	-	-	-

σ_x = 718.1

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Paul C. Rizzo Associates, Inc.
Consultants

By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Sheet No. A19 of A25
Chkd.By FAM Date 09.18-09 Project No. 07-3891

Low Flow Frequency Distribution (log Pearson Type III) for Danville Gage Station

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
1	0.56	558	1964	2.747	-0.454	0.207	-0.0939	0.1110	2	0.5	0.5	2.0000	-0.0188	1,577
2	0.72	722	1939	2.859	-0.343	0.117	-0.0402	-	10	0.1	0.9	1.1111	1.2930	2,649
3	0.84	839	1963	2.924	-0.277	0.077	-0.0213	-	25	0.04	0.96	1.0417	1.7886	3,222
4	0.84	840	1999	2.924	-0.277	0.077	-0.0212	-	50	0.02	0.98	1.0204	2.1127	3,663
5	0.86	855	1908	2.932	-0.269	0.072	-0.0195	-	100	0.01	0.99	1.0101	2.4079	4,116
6	0.88	876	1955	2.943	-0.259	0.067	-0.0173	-	200	0.005	0.995	1.0050	2.6802	4,584
7	0.89	888	1962	2.948	-0.253	0.064	-0.0161	-	-	-	-	-	-	-
8	0.90	900	1965	2.954	-0.247	0.061	-0.0150	-	-	-	-	-	-	-
9	0.92	918	1959	2.963	-0.238	0.057	-0.0135	-	-	-	-	-	-	-
10	0.92	920	1913	2.964	-0.237	0.056	-0.0134	-	-	-	-	-	-	-
11	0.92	920	1930	2.964	-0.237	0.056	-0.0134	-	-	-	-	-	-	-
12	0.92	920	1932	2.964	-0.237	0.056	-0.0134	-	-	-	-	-	-	-
13	0.95	952	1941	2.979	-0.222	0.049	-0.0110	-	-	-	-	-	-	-
14	0.98	982	1991	2.992	-0.209	0.044	-0.0091	-	-	-	-	-	-	-
15	0.99	991	1953	2.996	-0.205	0.042	-0.0086	-	-	-	-	-	-	-
16	1.02	1,020	1936	3.009	-0.192	0.037	-0.0071	-	-	-	-	-	-	-

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PAUL C. RIZZO ASSOCIATES, INC.
CONSULTANTS

By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Project No. 07-3891
Chkd.By FM Date 09-18-09

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)^2	(log X - (log X)bar)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
17	1.06	1,060	1966	3.025	-0.176	0.031	-0.0054	-	-	-	-	-	-	-
18	1.09	1,090	2002	3.037	-0.164	0.027	-0.0044	-	-	-	-	-	-	-
19	1.10	1,100	1910	3.041	-0.160	0.026	-0.0041	-	-	-	-	-	-	-
20	1.11	1,110	1954	3.045	-0.156	0.024	-0.0038	-	-	-	-	-	-	-
21	1.12	1,120	1909	3.049	-0.152	0.023	-0.0035	-	-	-	-	-	-	-
22	1.15	1,150	1949	3.061	-0.140	0.020	-0.0028	-	-	-	-	-	-	-
23	1.21	1,210	1911	3.083	-0.118	0.014	-0.0017	-	-	-	-	-	-	-
24	1.21	1,210	1948	3.083	-0.118	0.014	-0.0017	-	-	-	-	-	-	-
25	1.22	1,220	1923	3.086	-0.115	0.013	-0.0015	-	-	-	-	-	-	-
26	1.22	1,220	1931	3.086	-0.115	0.013	-0.0015	-	-	-	-	-	-	-
27	1.24	1,240	1907	3.093	-0.108	0.012	-0.0012	-	-	-	-	-	-	-
28	1.24	1,240	1980	3.093	-0.108	0.012	-0.0012	-	-	-	-	-	-	-
29	1.25	1,250	1943	3.097	-0.104	0.011	-0.0011	-	-	-	-	-	-	-
30	1.27	1,270	1944	3.104	-0.097	0.009	-0.0009	-	-	-	-	-	-	-
31	1.28	1,280	2005	3.107	-0.094	0.009	-0.0008	-	-	-	-	-	-	-
32	1.29	1,290	1952	3.111	-0.091	0.008	-0.0007	-	-	-	-	-	-	-
33	1.30	1,300	1983	3.114	-0.087	0.008	-0.0007	-	-	-	-	-	-	-
34	1.31	1,310	1934	3.117	-0.084	0.007	-0.0006	-	-	-	-	-	-	-

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*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
35	1.31	1,310	1957	3.117	-0.084	0.007	-0.0006	-	-	-	-	-	-	-
36	1.31	1,310	1961	3.117	-0.084	0.007	-0.0006	-	-	-	-	-	-	-
37	1.40	1,400	1929	3.146	-0.055	0.003	-0.0002	-	-	-	-	-	-	-
38	1.42	1,420	1997	3.152	-0.049	0.002	-0.0001	-	-	-	-	-	-	-
39	1.43	1,430	1982	3.155	-0.046	0.002	-0.0001	-	-	-	-	-	-	-
40	1.45	1,450	1969	3.161	-0.040	0.002	-0.0001	-	-	-	-	-	-	-
41	1.45	1,450	1988	3.161	-0.040	0.002	-0.0001	-	-	-	-	-	-	-
42	1.47	1,470	1940	3.167	-0.034	0.001	0.0000	-	-	-	-	-	-	-
43	1.48	1,480	1995	3.170	-0.031	0.001	0.0000	-	-	-	-	-	-	-
44	1.51	1,510	1993	3.179	-0.022	0.000	0.0000	-	-	-	-	-	-	-
45	1.54	1,540	1971	3.188	-0.014	0.000	0.0000	-	-	-	-	-	-	-
46	1.57	1,570	1985	3.196	-0.005	0.000	0.0000	-	-	-	-	-	-	-
47	1.58	1,580	1970	3.199	-0.002	0.000	0.0000	-	-	-	-	-	-	-
48	1.60	1,600	1912	3.204	0.003	0.000	0.0000	-	-	-	-	-	-	-
49	1.61	1,610	1987	3.207	0.006	0.000	0.0000	-	-	-	-	-	-	-
50	1.63	1,630	1947	3.212	0.011	0.000	0.0000	-	-	-	-	-	-	-
51	1.64	1,640	1906	3.215	0.014	0.000	0.0000	-	-	-	-	-	-	-
52	1.64	1,640	1951	3.215	0.014	0.000	0.0000	-	-	-	-	-	-	-

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Chkd.By FAM Date 09-18-09 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

m	Gage Station Data (Danville)			Log Pearson Type III Distribution											
	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)^2	(log X - (log X)bar)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
53	1.66	1,660	1989	3.220	0.019	0.000	0.0000	-	-	-	-	-	-	-
54	1.68	1,680	2001	3.225	0.024	0.001	0.0000	-	-	-	-	-	-	-
55	1.70	1,700	1914	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
56	1.70	1,700	1915	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
57	1.70	1,700	1918	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
58	1.70	1,700	1998	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
59	1.71	1,710	1968	3.233	0.032	0.001	0.0000	-	-	-	-	-	-	-
60	1.71	1,710	1981	3.233	0.032	0.001	0.0000	-	-	-	-	-	-	-
61	1.72	1,720	1938	3.236	0.034	0.001	0.0000	-	-	-	-	-	-	-
62	1.73	1,730	1933	3.238	0.037	0.001	0.0001	-	-	-	-	-	-	-
63	1.73	1,730	1935	3.238	0.037	0.001	0.0001	-	-	-	-	-	-	-
64	1.80	1,800	1922	3.255	0.054	0.003	0.0002	-	-	-	-	-	-	-
65	1.81	1,810	1919	3.258	0.057	0.003	0.0002	-	-	-	-	-	-	-
66	1.81	1,810	1921	3.258	0.057	0.003	0.0002	-	-	-	-	-	-	-
67	1.81	1,810	1926	3.258	0.057	0.003	0.0002	-	-	-	-	-	-	-
68	1.90	1,900	1979	3.279	0.078	0.006	0.0005	-	-	-	-	-	-	-
69	1.92	1,920	1928	3.283	0.082	0.007	0.0006	-	-	-	-	-	-	-
70	1.96	1,960	1937	3.292	0.091	0.008	0.0008	-	-	-	-	-	-	-

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Chkd.By FAM Date 09-18-09 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
71	1.96	1,960	1974	3.292	0.091	0.008	0.0008	-	-	-	-	-	-	-
72	1.97	1,970	1984	3.294	0.093	0.009	0.0008	-	-	-	-	-	-	-
73	1.99	1,990	1972	3.299	0.098	0.010	0.0009	-	-	-	-	-	-	-
74	2.00	2,000	1920	3.301	0.100	0.010	0.0010	-	-	-	-	-	-	-
75	2.03	2,030	1927	3.307	0.106	0.011	0.0012	-	-	-	-	-	-	-
76	2.04	2,040	1946	3.310	0.109	0.012	0.0013	-	-	-	-	-	-	-
77	2.06	2,060	1916	3.314	0.113	0.013	0.0014	-	-	-	-	-	-	-
78	2.10	2,100	1960	3.322	0.121	0.015	0.0018	-	-	-	-	-	-	-
79	2.11	2,110	1978	3.324	0.123	0.015	0.0019	-	-	-	-	-	-	-
80	2.14	2,140	1956	3.330	0.129	0.017	0.0022	-	-	-	-	-	-	-
81	2.15	2,150	1917	3.332	0.131	0.017	0.0023	-	-	-	-	-	-	-
82	2.15	2,150	1925	3.332	0.131	0.017	0.0023	-	-	-	-	-	-	-
83	2.15	2,150	1950	3.332	0.131	0.017	0.0023	-	-	-	-	-	-	-
84	2.16	2,160	1977	3.334	0.133	0.018	0.0024	-	-	-	-	-	-	-
85	2.20	2,200	1958	3.342	0.141	0.020	0.0028	-	-	-	-	-	-	-
86	2.20	2,200	1986	3.342	0.141	0.020	0.0028	-	-	-	-	-	-	-
87	2.27	2,270	1924	3.356	0.155	0.024	0.0037	-	-	-	-	-	-	-
88	2.30	2,300	1973	3.362	0.161	0.026	0.0041	-	-	-	-	-	-	-

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Chkd.By FRM Date 09-18-09 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	$(\log X - (\log X)_{bar})^2$	$(\log X - (\log X)_{bar})^3$	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
89	2.38	2,380	1942	3.377	0.175	0.031	0.0054	-	-	-	-	-	-	-
90	2.49	2,490	1975	3.396	0.195	0.038	0.0074	-	-	-	-	-	-	-
91	2.64	2,640	1996	3.422	0.221	0.049	0.0107	-	-	-	-	-	-	-
92	2.70	2,700	1967	3.431	0.230	0.053	0.0122	-	-	-	-	-	-	-
93	2.83	2,830	2000	3.452	0.251	0.063	0.0158	-	-	-	-	-	-	-
94	2.87	2,870	1992	3.458	0.257	0.066	0.0169	-	-	-	-	-	-	-
95	3.09	3,090	1990	3.490	0.289	0.083	0.0241	-	-	-	-	-	-	-
96	3.22	3,220	1945	3.508	0.307	0.094	0.0289	-	-	-	-	-	-	-
97	3.35	3,350	2004	3.525	0.324	0.105	0.0340	-	-	-	-	-	-	-
98	3.37	3,370	1994	3.528	0.327	0.107	0.0348	-	-	-	-	-	-	-
99	3.64	3,640	2006	3.561	0.360	0.130	0.0467	-	-	-	-	-	-	-
100	4.10	4,100	1976	3.613	0.412	0.169	0.0698	-	-	-	-	-	-	-
101	4.34	4,340	2003	3.637	0.436	0.190	0.0831	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
Avg. =	X_{bar}=	1,718	$(logX)_{bar}$ =	3.201	-	-	-	-	-	-	-	-	-	-
Sum =	-	173,561	-	323.310	-	2.947	0.0551	-	-	-	-	-	-	-

$\sigma_{log\,x}$ = 0.172

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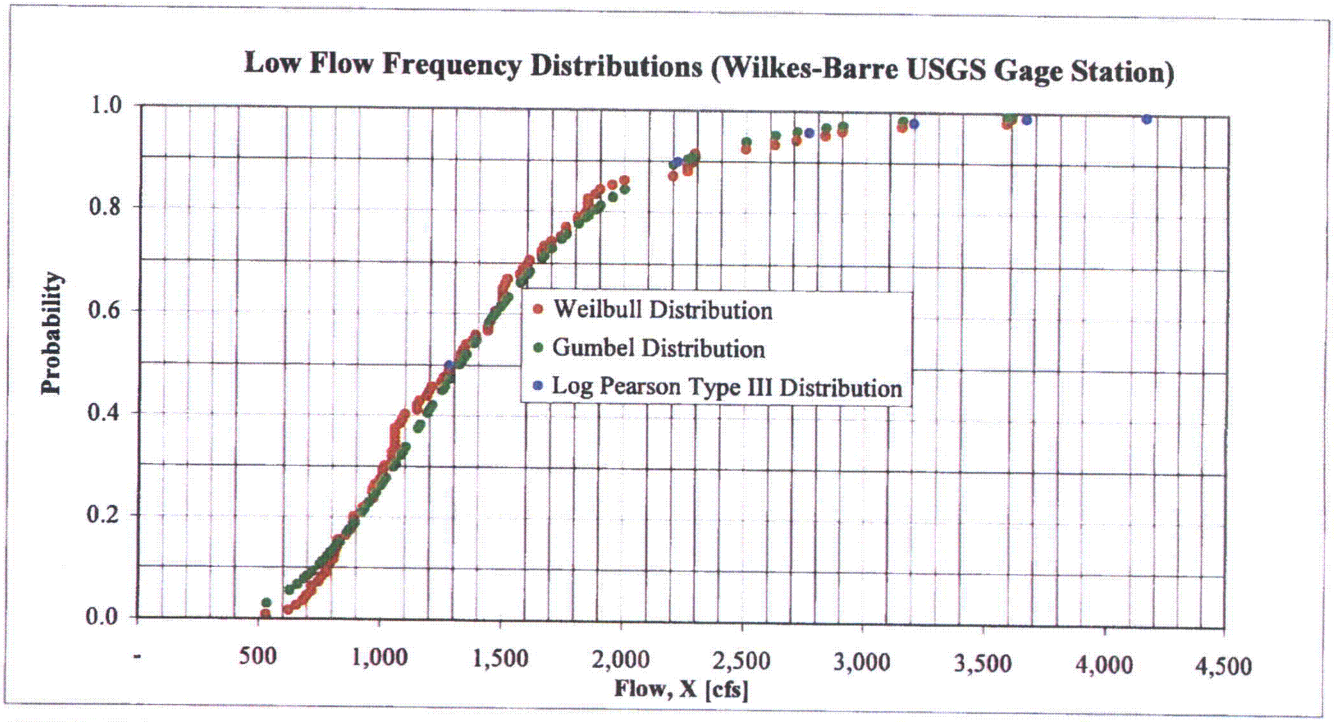
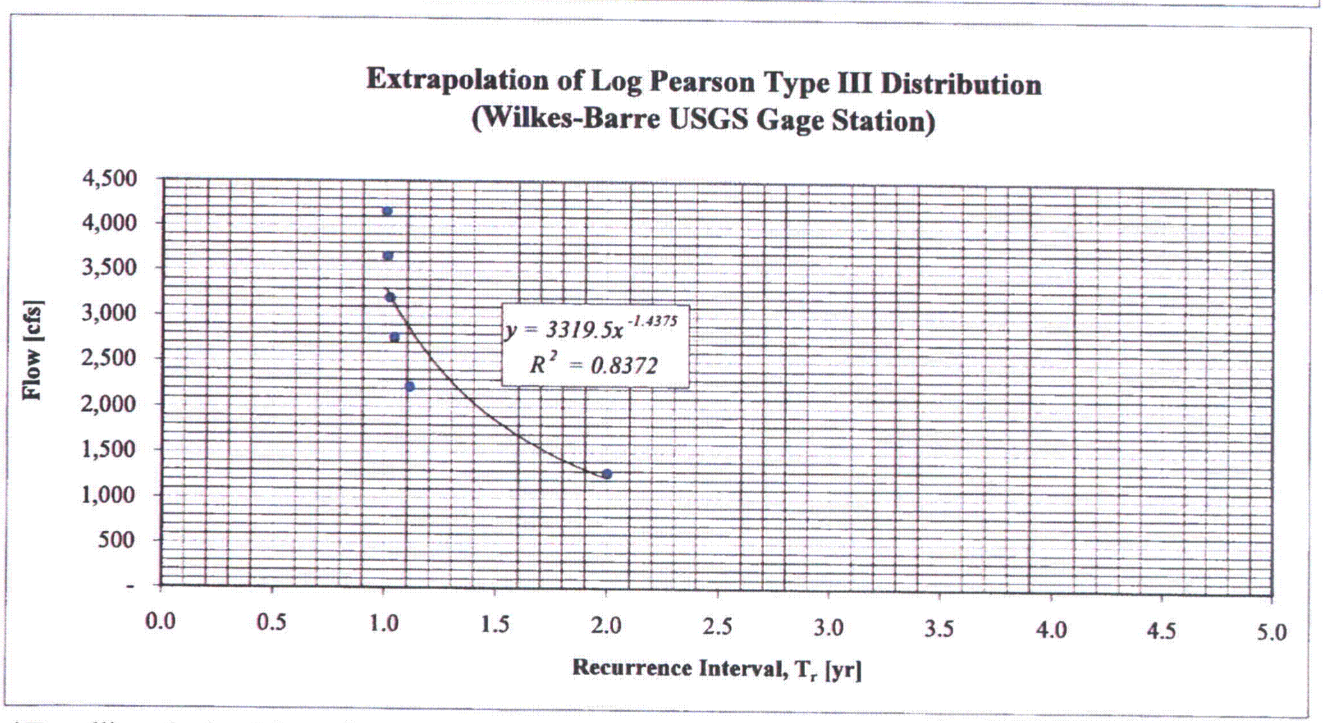
Attachment B

Low Flow Frequency Distribution Plots for Wilkes-Barre and Danville USGS Gage Stations





*Trendline obtained from the extrapolation of the log Pearson Type III Distribution used to estimate flow for a given recurrence interval.

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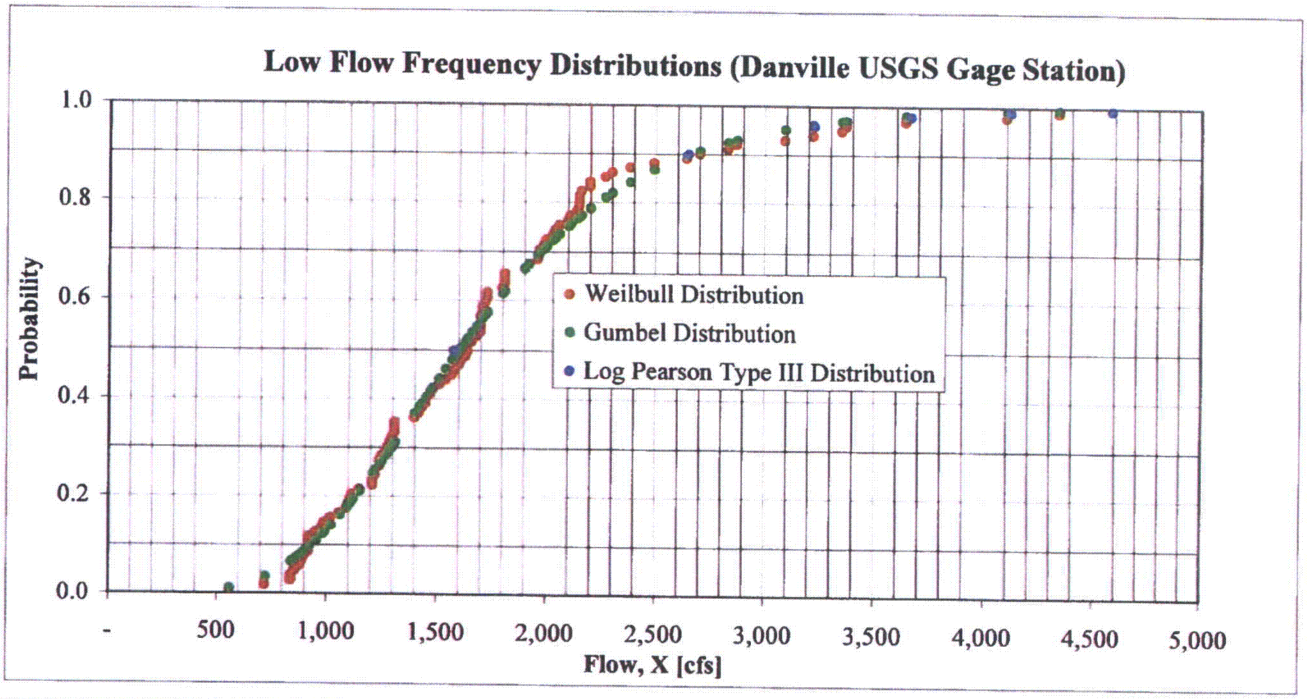

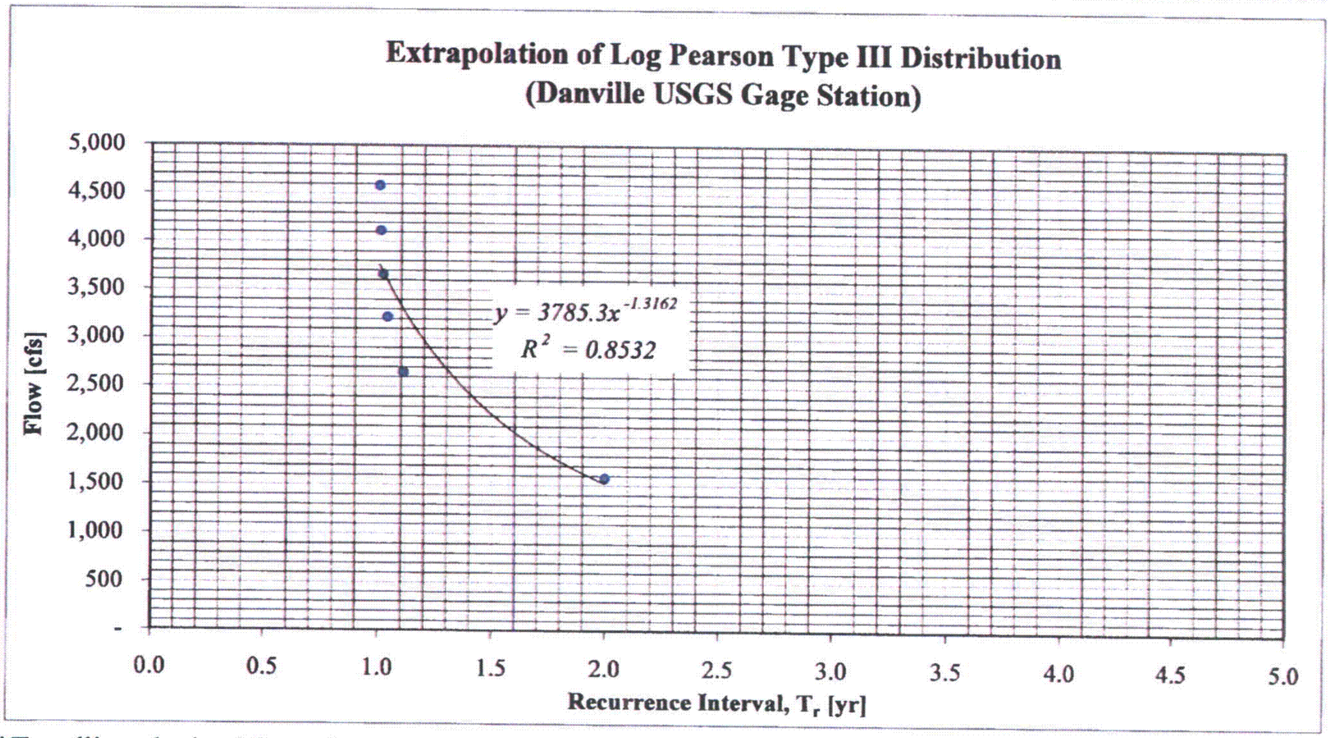

*Trendline obtained from the extrapolation of the log Pearson Type III Distribution used to estimate flow for a given recurrence interval.

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Reference 1

"Water-Resource Engineering" Text
(Frequency Distribution Formulas and Table A-5 Included)

WATER-RESOURCES ENGINEERING

Fourth Edition

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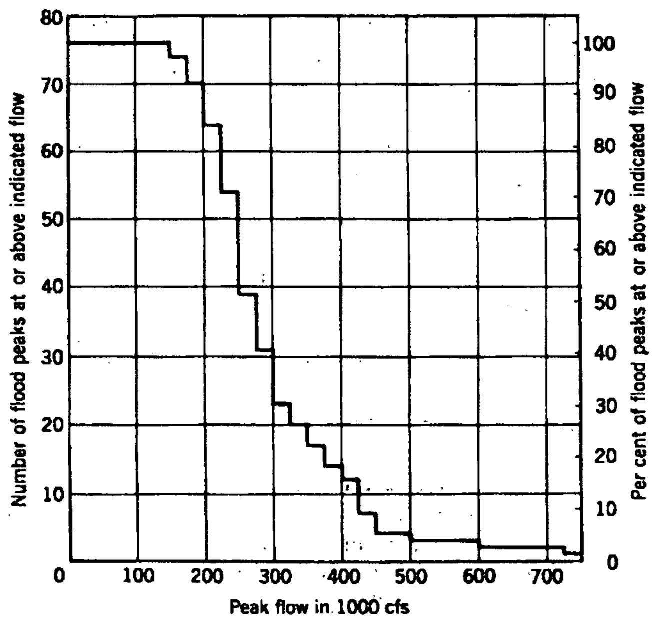


FIGURE 5.2
Integrated histogram of annual flood peaks for the Susquehanna River at Harrisburg, Pennsylvania (1874–1949).

5.2 Recurrence Interval

The recurrence interval[1] is defined as the average interval in years between the occurrence of a flood of specified magnitude and an equal or larger flood. The *m*th largest flood in a data series has been equaled or exceeded *m* times in the period of record. *N* years and an estimate of its recurrence interval T_r as given by the Weilbull formula is

$$T_r = \frac{N+1}{m} \tag{5.1}$$

Several other formulas have been suggested for the calculation of recurrence interval or return period. The disagreement between the various formulas is limited to the larger floods, where *m* is small. If *m* equals 5 or more, the calculated values of T_r by all methods are almost identical. Equation (5.1) can be used to define *plotting positions* (Fig. 5.3), which provide a good estimate of flood flows with return periods of less than 20 yr.

[1] Recurrence interval is also referred to as *return period.* There is no implication that floods with a return period of T_r will recur precisely T_r years apart. For example, one would expect the 5-yr flood to be equaled or exceeded approximately 20 times in a 100-yr period. The recurrence could occur in successive years or there might be a span of considerably more than 5 yr between recurrences.

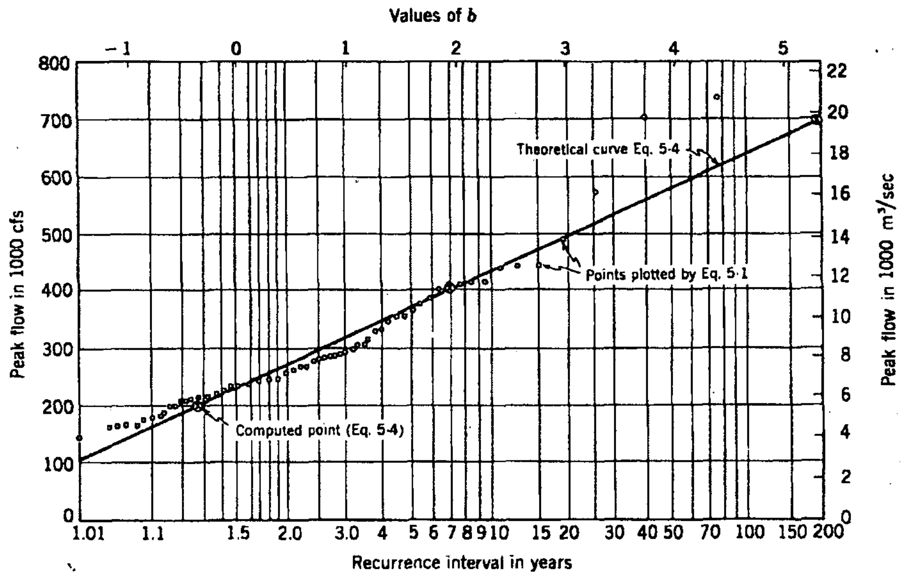


FIGURE 5.3
Frequency curve of annual floods for the Susquehanna River at Harrisburg, Pennsylvania (1874–1949).

If an event has a true recurrence interval of T_r years, then the probability P that it will be equaled or exceeded in any one year is

$$P = \frac{1}{T_r} \qquad (5.2)$$

Since the only possibilities are that the event will or will not occur in any year, the probability that it will not occur in a given year is $1 - P$. From the principles of probability, the probability J that at least one event that equals or exceeds the T_r-year event will occur in any series of N years is

$$J = 1 - (1 - P)^N \qquad (5.3)$$

This equation is derived as follows:

P is the probability of the occurrence of an event
$1 - P$ is the probability that the event will not occur.
$(1 - P)(1 - P)$ is the probability the event will not occur in two successive years.
$(1 - P)^3$ is the probability that the event will not occur in three successive years.
$(1 - P)^N$ is the probability that the event will not occur during a span of N successive years.
Hence $J = 1 - (1 - P)^N$ is the probability that the event will occur during a span of N years.

TABLE 5.2
Probability that an event of given recurrence interval will be equaled or exceeded during periods of various lengths

	Probability *J* for Various Periods							
T_p, yr	1 yr	5 yr	10 yr	25 yr	50 yr	100 yr	200 yr	500 yr
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	0.5	0.97	0.999	*	*	*	*	*
5	0.2	0.67	0.89	0.996	*	*	*	*
10	0.1	0.41	0.65	0.93	0.995	*	*	*
50	0.02	0.10	0.18	0.40	0.64	0.87	0.98	*
100	0.01	0.05	0.10	0.22	0.40	0.63	0.87	0.993
200	0.005	0.02	0.05	0.12	0.22	0.39	0.63	0.92

* In these cases *J* can never be exactly 1, but for all practical purposes its value may be taken as unity.

Table 5.2, which has been computed from Eq. (5.3), shows that there are 4 chances in 10 that the 100-yr flood (or greater) will occur in any 50-yr period and even a 22 percent probability that the 200-yr flood (or greater) might occur in the 50-yr period. On the other hand, there are 36 chances in 100 that the 50-yr flood will not occur in any 50-yr period. Equation 5.3 (or Table 5.2) may be used to estimate the risk of failure during the lifetime of a project when using different design criteria.

Table 5.2 illustrates also that there can be no inference that the "*N*-year flood" will be equaled or exceeded exactly once in every period of *N* years. All that is meant is that in a long period, say 10,000 years, there will be 10,000/*N* floods equal to or greater than the *N*-year flood. All such floods might occur in consecutive years, but this is not very probable.

If the design flood for a particular project is to have a recurrence interval much shorter than the period of record, its value may be determined by plotting peak flows versus T_r as computed from Eq. (5.1) and sketching a curve through the plotted points (Fig. 5.3). Because of inaccuracies in the plotted positions of the larger floods, a line sketched to conform to these floods may depart substantially from the location of the true frequency curve.

5.3 Statistical Methods for Estimating the Frequency of Rare Events

With an extremely long period of record it would be possible to use a smaller class interval, and Fig. 5.1 might approach a smooth frequency distribution such as Fig. 5.4. The ordinates of Fig. 5.4 are probability density and the abscissas are the magnitudes of the floods. The ratio of the area under the curve above any magnitude X_1 to the area under the entire curve is the probability that X_1 will be equaled or exceeded in any year.

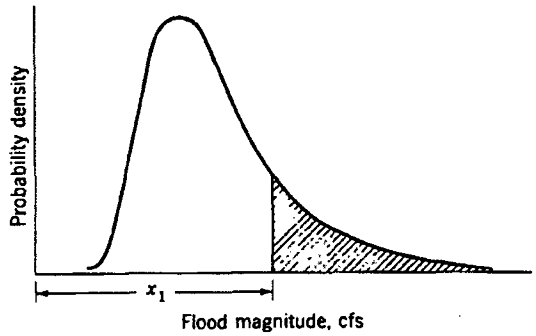


FIGURE 5.4
Idealized flood frequency distribution.

Many kinds of events conform to one of several standard frequency distributions that have been studied at length and the equation of the distribution well established. The probability of such events can be determined quite easily. Only a very large number of samples (i.e., a long record length) will permit accurate definition of a distribution, and no streamflow records are long enough to positively establish the appropriate distribution. It is known that X must be greater than zero and that future floods will exceed those that have been observed.

Several distributions have been suggested[1] as appropriate for streamflow, but there is no real proof of their validity. Fisher and Tippett[2] showed that if one selected the largest event from each of many large samples, the distribution of these extreme values was independent of the original distribution and conformed to a limiting function. Gumbel[3] suggested that this distribution of extreme values was appropriate for flood analysis since the annual flood could be assumed to be the largest of a sample of 365 possible values each year. Based on the argument that the distribution of floods is unlimited, i.e., that there is no physical limit to the maximum flood, he proposed that the probability P of the occurrence of a value equal to or greater than any X be expressed as

$$P = 1 - e^{-e^{-b}} \tag{5.4}$$

where e is the base of Natural logarithms and b is given by

$$b = \frac{1}{0.7797\sigma}(X - \bar{X} + 0.45\sigma) \tag{5.5}$$

[1] H. A. Foster, Theoretical Frequency Curves, *Trans. ASCE*, Vol. 87, pp. 142–173, 1924; Allen Hazen, "Flood Flows," Wiley, New York, 1930; and L. R. Beard, Statistical Analysis in Hydrology, *Trans. ASCE*, Vol. 103, pp. 1110–1160, 1943.

[2] R. A. Fisher and L. H. C. Tippett, Limiting Forms of the Frequency Distribution of the Largest or Smallest Member of a Sample, *Proc. Cambridge Philos. Soc.*, Vol. 24, pp. 180–190, 1928.

[3] E. J. Gumbel, Floods Estimated by the Probability Method, *Eng. News-Record*, Vol. 134, pp. 833–837, 1945.

In Eq. (5.5), X is the flood magnitude with the probability P, $\bar{X}$ is the arithmetic average of all floods in the series, and σ is the standard deviation of the series computed from

$$\sigma = \left[\frac{\sum (X - \bar{X})^2}{N - 1}\right]^{1/2} \tag{5.6}$$

where N is the number of items in the series (the number of years of record). The probability P is related to the recurrence interval T_r by Eq. (5.2). Values of b corresponding to various return periods are given in Appendix A-4.

Example 5.1. Using the data of Table 5.1, find the theoretical recurrence interval for a flood flow of 700,000 cfs using the Gumbel approach.

Solution. Expressing all flows in thousands of cfs, from the table, $\bar{X} = 287.8$ and $\sigma = (962{,}367/75)^{0.5} = 113.3$. When $X = 700$,

$$b = \frac{1}{0.7797 \times 113.3}[700 - 288 + 0.45(113.3)] = 5.24$$

The recurrence interval for $X = 700$ is, from Eqs. (5.2) and (5.4),

$$T_r = \frac{1}{1 - e^{-e^{-5.24}}} = 189 \text{ yr}$$

By the same method $T_r = 1.28$ yr when $X = 200$ and 6.89 yr when $X = 400$. These points are shown on Fig. 5.3 by the large circles.

The plotting paper used for Fig. 5.3 is constructed by laying out on a linear scale of b the corresponding values of $T_r = 1/P$ from Eq. (5.4). Thus the computed line will be straight, and it is sufficient to calculate the return period corresponding to two flows. A third point is a convenient check.

In 1967, the U.S. Water Resources Council[1] adopted the log Pearson Type III distribution (of which the lognormal is a special case) as a standard for use by federal agencies. The purpose was to achieve standardization of procedures. The recommended procedure[2] is to convert the series to logarithms and compute the mean, standard deviation, and skew coefficient g, which is

$$g = \frac{N \sum (\log X - \overline{\log X})^3}{(N - 1)(N - 2)(\sigma_{\log X})^3} \tag{5.7}$$

The values of X for various periods are computed from

$$\log X = \overline{\log X} + K\sigma_{\log X} \tag{5.8}$$

→ magnitude of the flow = $10^{\log X}$

[1] A Uniform Technique for Determining Flood Flow Frequencies, *U.S. Water Resources Council Hydrol. Comm. Bull.* 15, December 1967, Revised June 1977.

[2] Subcommittee on Hydrology, Methods of Flow Frequency Analysis, *Interagency Comm. Water Resources Bull.* 13, U.S. Government Printing Office, Washington, D.C., April 1966.

Table A-4 Values of the reduced variate *b* corresponding to various values of return period and probability of exceedance [Eq. (5.5)]

Reduced variate b	Return period t_p = T_R	Probability of exceedance P
0.000	1.58	0.632
0.367	2.00	0.500
0.579	2.33	0.429
1.500	5.00	0.200
2.250	10.0	0.100
2.970	20.0	0.050
3.902	50.0	0.020
4.600	100	0.010
5.296	200	0.005
6.000	403	0.0025

Table A-5 Values of *K* for use with the log Pearson type III distribution

Skew coefficient g	Recurrence interval, yr: 2	10	25	50	100	200
	Chance, %: 50	10	4	2	1	0.5
3.0	−0.396	1.180	2.278	3.152	4.051	4.970
2.5	−0.360	1.250	2.262	3.048	3.845	4.652
2.0	−0.307	1.302	2.219	2.912	3.605	4.298
1.8	−0.282	1.318	2.193	2.848	3.499	4.147
1.6	−0.254	1.329	2.163	2.780	3.388	3.990
1.4	−0.225	1.337	2.128	2.706	3.271	3.828
1.2	−0.195	1.340	2.087	2.626	3.149	3.661
1.0	−0.164	1.340	2.043	2.542	3.022	3.489
0.9	−0.148	1.339	2.018	2.498	2.957	3.401
0.8	−0.132	1.336	1.993	2.453	2.891	3.312
0.7	−0.116	1.333	1.967	2.407	2.824	3.223
0.6	−0.099	1.328	1.939	2.359	2.755	3.132
0.5	−0.083	1.323	1.910	2.311	2.686	3.041
0.4	−0.066	1.317	1.880	2.261	2.615	2.949
0.3	−0.050	1.309	1.849	2.211	2.544	2.856
0.2	−0.033	1.301	1.818	2.159	2.472	2.763
0.1	−0.017	1.292	1.785	2.107	2.400	2.670

(continued)

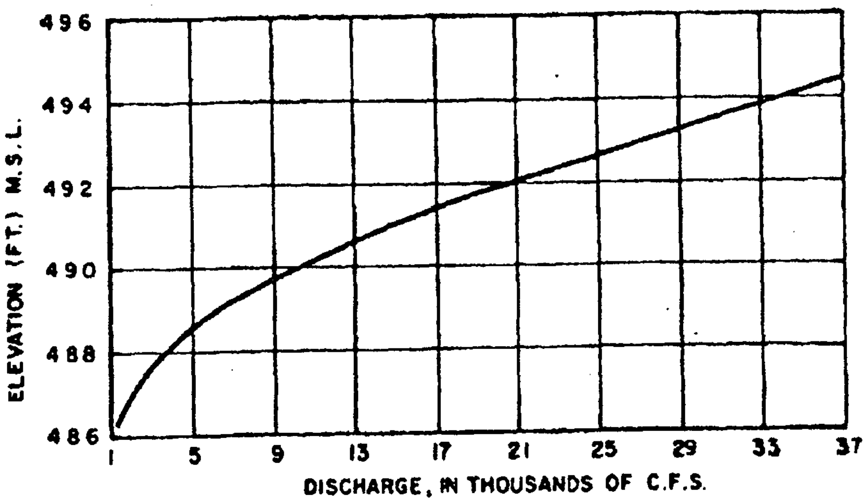
Skew coefficient g	Recurrence interval, yr: 2	10	25	50	100	200
	Chance, %: 50	10	4	2	1	0.5
0	0	1.282	1.751	2.054	2.326	2.576
−0.1	0.017	1.270	1.716	2.000	2.252	2.482
−0.2	0.033	1.258	1.680	1.945	2.178	2.388
−0.3	0.050	1.245	1.643	1.890	2.104	2.294
−0.4	0.066	1.231	1.606	1.834	2.029	2.201
−0.5	0.083	1.216	1.567	1.777	1.955	2.108
−0.6	0.099	1.200	1.528	1.720	1.880	2.016
−0.7	0.116	1.183	1.488	1.663	1.806	1.926
−0.8	0.132	1.166	1.448	1.606	1.733	1.837
−0.9	0.148	1.147	1.407	1.549	1.660	1.749
−1.0	0.164	1.128	1.366	1.492	1.588	1.664
−1.2	0.195	1.086	1.282	1.379	1.449	1.501
−1.4	0.225	1.041	1.198	1.270	1.318	1.351
−1.6	0.254	0.994	1.116	1.166	1.197	1.216
−1.8	0.282	0.945	1.035	1.069	1.087	1.097
−2.0	0.307	0.895	0.959	0.980	0.990	0.995
−2.5	0.360	0.771	0.793	0.798	0.799	0.800
−3.0	0.396	0.660	0.666	0.666	0.667	0.667

Table A-6a Areas of circles (English units)

Diameter, in.	Area: in^2	ft^2
0.25	0.049	0.00034
0.5	0.196	0.00136
1.0	0.785	0.00545
2.0	3.142	0.0218
3.0	7.069	0.0491
4.0	12.57	0.0873
6.0	28.27	0.196
8.0	50.27	0.349
10.0	78.54	0.545
12.0	113.10	0.785

Reference 2

Impact Point Drainage Area (DA_{ip})
SSES Unit 1 & 2 FSAR



NOTES: ELEVATIONS MEASURED BY GAGE AT SUSQUEHANNA SITE

FLOWS MEASURED AT WILKES—BARRE AND DANVILLE. FLOW AT SITE OBTAINED BY INTERPOLATION ON BASIS OF DRAINAGE AREA.

DRAINAGE AREAS :

WILKES-BARRE 9960 SQ MILES (25795 SQ KM)
SUSQUEHANNA SITE 10200 SQ MI (26416 SQ KM)
DANVILLE 11220 SQ MI (29058 SQ KM)

FSAR REV. 46, 06/93

SUSQUEHANNA STEAM ELECTRIC STATION
UNITS 1 AND 2
FINAL SAFETY ANALYSIS REPORT

STAGE DISCHARGE CURVE, DISCHARGE RANGE 1000 - 37000 CFS

FSAR FIGURE 2.4-6

PP&L DRAWING

Reference 3

USGS / PaDEP: Computing Low Flow Statistics for Ungaged Sites Using Drainage Area Ratios

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

Computing Low-Flow Statistics for Ungaged Locations on Pennsylvania Streams By Use of Drainage-Area Ratios

Introduction

The U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Environmental Protection (PaDEP), developed low-flow statistics for approximately 2,800 ungaged locations on streams in Pennsylvania by use of streamflow statistics from streamflow-gaging stations and drainage-area ratios ranging from one-third to three times. These low-flow statistics will aid PaDEP in reviewing requests for permits associated with stream-water withdrawals from, and effluent discharges to, Pennsylvania streams.

Methodology

Low-flow statistics from 312 USGS streamflow-gaging stations (gages) were computed as described in Ehlke and Reed (1999). The gages used in the computations were active and discontinued stations with at least 10 years of continuous record and were representative of the hydrologic conditions encountered throughout Pennsylvania. The computed low-flow statistics include the **1-day 10-year low flow** $_{(Q1,10)}$ **7-day 10-year low flow (Q7,10), 30-day 10-year low flow (Q30,10), mean, median, harmonic mean**, and **flow-duration table.**

Regulation and diversion of streamflow can significantly modify low-flow discharges. Large reservoirs are often required to release a predetermined amount of water to supplement streamflow during droughts; diversions can decrease streamflow during droughts. Occasionally, these withdrawals are discharged to different stream basin, increasing the streamflow in the discharge basin. Regulation is defined for this website as a stream with an upstream flood-control reservoir(s) which controls 10 percent or more of the contributing basin. If regulation began while the gage was in operation, records were analyzed for pre-regulation, post-regulation, and entire period of record streamflow conditions. In the case of multiple upstream reservoirs controlling the streamflow, the year in which the reservoir was built that makes the cumulative controlled area equal to 10 percent determines the break in record. Because diversions are more difficult to quantify and are not always published, basin with diversion of streamflow were analyzed the same as a basin without any diversion.

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

The low-flow statistics presented in this web application were transferred upstream to one-third and downstream to three times the drainage area of a nearby, hydrologically similar gage. While statistics were computed for pre-regulation, post-regulation and the entire period of record for gages with upstream regulation, only the post-regulation conditions are transferred to bridges. To transfer either pre-regulation or entire period statistics to sites upstream and downstream based on drainage area ratios, follow the example shown below.

Example. Transfer the $Q_{7,10}$ computed from pre-regulation conditions from gage 01541500 on Clearfield Creek to a site upstream with a drainage area of 194 mi^2. The drainage area at the gage is 371 mi^2 and the $Q_{7,10}$ is 21 ft^3/s.

1 Determine the drainage area (DA) ratio:

$DA_{site} / DA_{gage} = 194 / 371 = 0.52$

2. Multiply the calculated ratio times the low-flow statistic at the gage:

$0.52*21=11 ft^3/s$

The period of record for a gage can also influence computed low-flow statistics. Short period of records which include one or more droughts can result in a lowered low-flow statistic. A gage which was operated for a short period during wet conditions, with the absence of any drought periods, can have associated elevated low-flow statistics. A gage should ideally have a period of record which contains both normal and drought conditions extended throughout a long period of time. The period of record shown for each gage in the website application should be inspected to ensure that the computed low-flow statistic is applicable to the specified needs of the user.

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

Low-flow statistics from gages were transferred to approximately 2,700 hydrologically similar (including streams affected by carbonate bedrock, mining, and regulation) ungaged locations upstream and downstream from the gages on the basis of drainage-area ratios (ratios). To determine a ratio range appropriate for transferring low-flow statistics, the $Q_{7,10}$ statistics from 74 gages reported by Ehlke and Reed (1999) were compared. To maximize the number of applicable paired gages used in the analysis, some gages were used in multiple paired comparisons. This analysis produced 92 comparisons from 46 paired gages that are hydrologically similar and have ratios ranging from 0.24 to 4.2 times.

Low-flow regionalization was last done in Pennsylvania by the USGS in 1982. Flippo (1982b) presented 12 regional regression equations for estimating $Q_{7,10}$ statistics at ungaged locations in Pennsylvania and reported that two-thirds of the regression estimates were expected to be within standard errors of estimate, that range from 20 to 45 percent (Flippo, 1982a, 1982b). For this study, the $Q_{7,10}$ statistic and the median standard error of estimate from Flippo (1 982b), 33 percent, were selected as analysis tools for testing the transferred statistics.The $Q_{7,10}$ statistic was chosen as the representative statistic because it is the only commonly used low-flow statistic the regression equations predict.

Results of the analyses are listed in table 1 and shown in figures 1, 2, and 3. Included in table 1 for each paired comparison are the gage numbers, periods of record by **climatic year**, drainage areas, drainage-area ratios, the $Q_{7,10}$ statistics reported in Ehlke and Reed (1999), the transferred $Q_{7,10}$ statistics that use the ratios, and the absolute percent differences between the reported and the transferred $Q_{7,10}$ statistics. The largest absolute percent difference, 125 percent, is at a 1.8 ratio, and the smallest percent difference, 0.29 percent, is at a 0.41 ratio (table 1).

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The relation between ratio and absolute percent difference for the 92 comparisons is shown in figure 1. Vertical solid and dashed lines are superimposed at ratio ranges of one-third to three times and one-half to two times, respectively. The median standard error of estimate for regression from Flippo (1982b), 33 percent, is superimposedas a horizontal dashed line for validity testing. Of the 76 comparisons that fall within the ratio range of one-third tothree times, 62, or 82 percent, have absolute percent differences less than or equal to the median standard error ofestimate for regression. Of the 64 comparisons that fall within the ratio range of one-half to two times, 53, or 83percent, have absolute percent differences less than or equal to the median standard error of estimate for regression.Extending the range from one-half to two times to one-third to three times results in 12 additional sites, 9 of whichhave absolute percent differences less than or equal to the median standard error of estimate for regression. Themedian absolute percent difference for both the one-third to three times ratio and the one-half to two times ratioranges is 14 percent, which is lower than the median standard error of estimate for regression from Flippo (1982b). Ofthe 16 comparisons that fall outside the one-third to three times ratio, only 3, or 19 percent, have absolute percentdifferences less than the median standard error of estimate for regression.

A comparison between the computed $Q_{7,10}$ statistics as reported in Ehlke and Reed (1999) and the 76 transferred $Q_{7,10}$ statistics that are within the one-third to three times ratio is shown in figure 2. The greatest outlier occurs at 3,210 ft^3/s, with a transferred $Q_{7,10}$ equalling 2,110 ft^3/s (fig. 2). An analysis of the relation between absolute percent difference and drainage area, not included herein, revealed no bias.

The relation between the absolute percent difference and the gage period of record for the 76 transferred $Q_{7,10}$ statistics that are within the one-third to three times ratio is shown in figure 3. Vertical dashed lines are superimposed at 20 and 40 years of record, and the median standard error of estimate for regression from Flippo (1982b), 33 percent, is superimposed as a horizontal dashed line. Of the 33 gages with less than 20 years of record, 8, or 24 percent, have absolute percent differences that exceed the median standard error of estimate for regression. Of the 20 gages with periods of record between 20 and 40 years, 4, or 20 percent, have absolute percent differences that exceed the median standard error of estimate for regression. And of the 23 gages with more than 40 years of record, only 1, or 4 percent, has an absolute percent difference that exceeds the median standard error of estimate for regression.

Conclusions

While the analyses discussed herein do not categorically preclude the use of ratios outside the one-third to three times range to transfer computed low-flow statistics on hydrologically similar streams in Pennsylvania, they do suggest the one-third to three times ratio is as appropriate as a one-half to two times ratio as a maximum range. In addition, the validity tests discussed herein indicate that transferring low-flow statistics computed at long-term gagesto hydrologically similar, upstream and downstream ungaged locations within a one-third to three times ratio range isas reliable as, if not more than, the regression equations developed by Flippo (1982b) to estimate $Q_{7,10}$. Because the$Q_{7,10}$ statistic is representative of what is often considered very low-flow conditions, the method discussed hereinshould produce similar results with other low-flow statistics.

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

***Table1.** Comparison of 7-day 10-year low -flow statistics $_{(Q7,10)}$ with those developed using drainage-area ratios as a basis for transferring statistics upstream and downstream to hydrologically similar locations*

[climatic year, 12-month period from April 1 to March 31; mi², square miles; Q7,10 statistics from Ehlke and Reed (1999); ft³/s, cubic feet per second; transferred $_{Q7,10}$ values were computed using unrounded drainage-area ratios]

U.S. Geological Survey Stream flow-gaging station	Period of record (climatic year)	Drainage area (mi²)	Drainage-area ratio	Q7,10 (ft³/s)	Transferred Q7,10 (ft³/s)	Absolute value of percent difference
01440400	1959-96	65.9	0.25	7.54	12.4	64
01442500	1952-95	259	3.9	48.7	29.6	39
01447500	1945-96	91.7	.28	13.3	19.2	44
01448000	1918-59	322	3.5	67.4	46.7	31
01453000	1943-94	1,279	.94	358	491	37
01454700	1968-95	1,359	1.1	522	380	27
01465770	1966-81	5.08	.24	.44	.54	23
01465798	1967-94	21.4	4.2	2.26	1.85	18
01467042	1966-81	37.9	.76	9.29	9.89	6.5
01467048	1967-94	49.8	1.3	13.0	12.2	6.2
01467086	1967-88	16.6	.55	4.36	1.93	56
01467087	1984-94	30.4	1.8	3.55	7.98	125
01467086	1967-88	16.6	.49	4.36	3.23	26
01467089	1967-81	33.8	2.0	6.58	8.88	35
01467087	1984-94	30.4	.90	3.55	5.92	67
01467089	1967-81	33.8	1.1	6.58	3.95	40
01467500	1945-69	53.4	.40	17.1	17.7	3.5
01468500	1949-95	133	2.5	44.2	42.6	3.6
01470960	1967-78	175	.83	38.5	39.4	2.3
01471000	1952-79	211	1.2	47.5	46.4	2.3
01470960	1981-94	175	.83	31.3	36.2	16
01471000	1981-94	211	1.2	43.6	37.7	14
01471510	1979-95	880	.77	245	216	12
01472000	1935-96	1,147	1.3	281	319	14
01472198	1985-95	38.0	.25	7.39	3.60	51
01472500	1886-1913	152	4.0	14.4	29.6	106
01472500	1886-1913	152	.54	14.4	8.17	43
01473000	1916-55	279	1.8	15.0	26.4	76
01480300	1962-94	18.7	.41	3.39	3.38	.29
01480500	1945-94	45.8	2.4	8.27	8.30	.36
01480700	1975-96	60.6	.67	14.5	19.3	33
01480870	1975-94	89.9	1.5	28.6	21.5	25
01516350	1978-96	153	.54	9.79	4.73	52
01518000	1940-76	282	1.8	8.71	18.0	110
01518862	1985-95	90.6	.30	1.14	.64	44
01520000	1953-76	298	3.3	2.10	3.75	79
01531500	1915-95	7,797	.89	581	601	3.4

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PAUL C. RIZZO ASSOCIATES, INC.
CONSULTANTS

By DW Date 7/22/2009 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) (Rev. 2) Sheet No. Ref3 8 of Ref3 12
Chkd.By FAM Date 09-18-09 Project No. 07-3891

Table1. Comparison of 7-day 10-year low-flow statistics $_{(Q7,10)}$ with those developed using drainage-area ratios as a basis for transferring statistics upstream and downstream to hydrologically similar locations

[climatic year, 12-month period from April 1 to March 31; mi², square miles; Q710 statistics from Ehlke and Reed (1999); ft³/s, cubic feet per second; transferred Q710 values were computed using unrounded drainage-area ratios]

U.S. Geological Survey Stream-flow-gaging station	Period of record (climatic year)	Drainage area (mi²)	Drainage-area ratio	Q7,10 (ft³/s)	Transferred Q7,10 (ft³/s)	Absolute value of percent difference
01533400	1978-96	8,720	1.1	672	650	3.3
01531500	1915-95	7,797	.78	581	643	11
01536500	1900-96	9,960	1.3	821	742	9.6
01534500	1961-96	108	.33	18.0	11.5	36
01536000	1961-95	332	3.1	35.2	55.3	57
01536500	1900-96	9,960	.89	821	898	9.4
01540500	1906-96	11,200	1.1	1,010	923	8.6
01536500	1981-96	9,960	.41	874	1,326	52
01570500	1981-96	24,100	2.4	3,210	2,110	34
01541200	1967-95	367	.77	43.6	45.5	4.4
01541303	1980-95	474	1.3	58.8	56.3	4.3
01546400	1985-95	58.5	.67	15.0	19.3	29
01546500	1942-94	87.2	1.5	28.7	22.4	22
01547200	1957-96	265	.78	99.9	75.0	25
01547500	1956-70	339	1.3	96.0	128	33
01548500	1919-95	604	.81	23.8	26.4	11
01549000	1910-20	750	1.2	32.8	29.6	9.8
01548500	1919-95	604	.64	23.8	24.2	1.7
01549700	1962-95	944	1.6	37.9	37.2	1.8
01551500	1958-95	5,682	.83	584	604	3.4
01553500	1962-95	6,847	1.2	728	704	3.3
01554000	1981-95	18,300	1.6	2,150	1,960	8.8
01540500	1981-95	11,220	.61	1,200	1,320	10
01554000	1981-96	18,300	.76	2,150	2,440	13
01570500	1981-96	24,100	1.3	3,210	2,830	12
01563500	1939-71	2,030	.61	241	222	7.9
01567000	1901-71	3,354	1.7	367	398	8.4
01570500	1892-1978	24,100	.93	2,530	2,510	.79
01576000	1933-96	25,990	1.1	2,710	2,730	.74
03016000	1943-96	3,660	.48	394	368	6.6
03031500	1934-95	7,671	2.1	772	826	7.0
03017500	1940-79	233	.50	16.4	12.2	26
03019000	1924-40	469	2.0	24.6	33.0	34
03020500	1934-96	300	.95	30.6	32.1	4.9
03021000	1911-32	315	1.0	33.7	32.1	4.7
03022500	1923-39	629	.63	31	45.6	47
03023500	1910-25	998	1.6	72.3	49.2	32

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

***Table1.** Comparison of 7-day 10-year low -flow statistics ($Q_{7,10}$) with those developed using drainage-area ratios as a basis for transferring statistics upstream and downstream to hydrologically similar locations*

[climatic year, 12-month period from April 1 to March 31; mi², square miles; $Q_{7,10}$ statistics from Ehlke and Reed (1999); ft³/s, cubic feet per second; transferred $Q_{7,10}$ values were computed using unrounded drainage-area ratios]

U.S. Geological Survey Stream-flow-gaging station	Period of record (climatic year)	Drainage area (mi²)	Drainage-area ratio	Q7,10 (ft³/s)	Transferred Q710 (ft³/s)	Absolute value of percent difference
03023500	1910-25	998	.97	72.3	60.2	17
03024000	1934-70	1,028	1.0	62.0	74.5	20
03028500	1954-94	204	.25	65.3	41.5	36
03029500	1954-96	807	4.0	164	258	57
03029000	1941-51	303	.38	25.3	21.6	15
03029500	1940-51	807	2.7	57.4	67.4	17
03029000	1941-51	303	.24	25.3	13.4	47
03031000	1943-53	1,246	4.1	55.1	104	89
03063000	1938-55	2,720	.62	290	286	1.4
03072500	1940-95	4,407	1.6	463	470	1.5
03072500	1940-95	4,407	.83	463	407	12
03075070	1935-95	5,340	1.2	494	561	14
03082500	1927-96	1,326	.77	209	244	17
03083500	1928-95	1,715	1.3	316	270	15
03100000	1913-22	152	.84	3.56	2.91	18
03102000	1921-32	181	1.2	3.47	4.24	22
03104000	1912-32	608	.77	14.7	12.5	15
03104500	1914-32	792	1.3	16.3	19.1	17

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

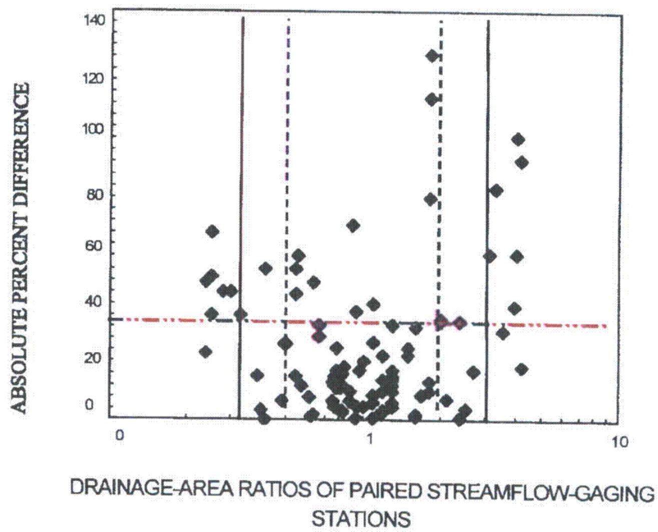

Figure 1.--Relation between drainage-area ratios and absolute percent differences for the streamflow-gaging stations (vertical, black solid lines encompass the one-third to three times ratio, vertical, blue dashed lines encompass the one-half to two times ratio, and horizontal red dashed line represents the median standard error of estimate for regression from Flippo, 1982b)

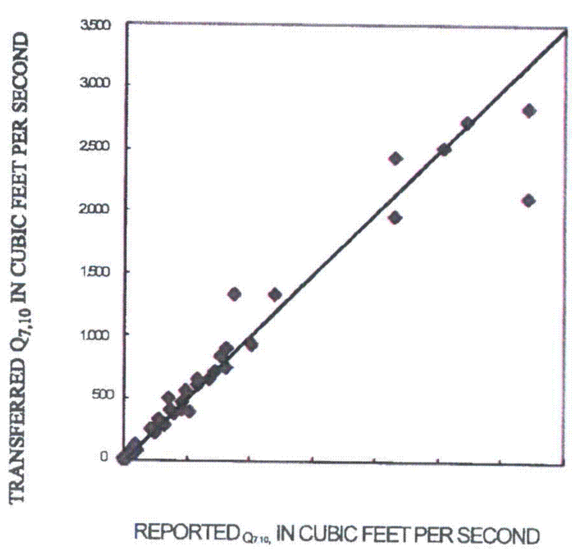

Figure 2.–Comparison between the Q7,10 statistics reported in Ehlke and Reed (1999) and the corresponding transferred Q7,10 statistics within the one-third to three times ratio range

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

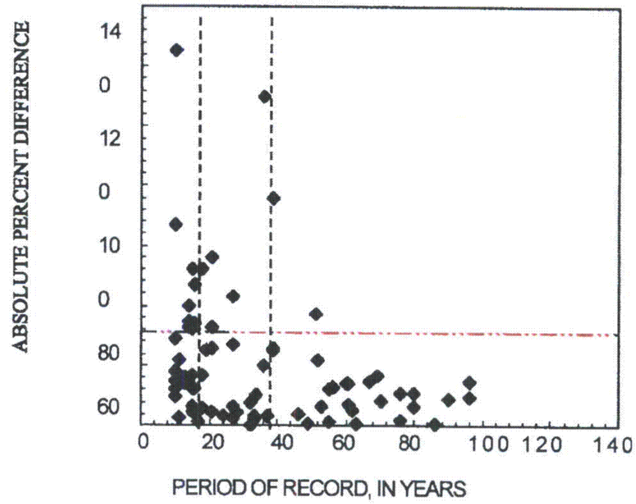

Figure 3.--Relation between the periods of record and the absolute percent differences (vertical, blue dashed lines represent 20 and 40 years of record, and horizontal red dashed line represents the median standard error of estimate for regression from Flippo, 1 982b)

Glossary

1-day 10-year low flow ($Q_{1,10}$), in cubic feet per second, is the average minimum streamflow expected for 1 day once every 10 years.

7-day 10-year low flow ($Q_{7,10}$), in cubic feet per second, is the average minimum streamflow expected for 7 consecutive days once every 10 years.

30-day 10-year low flow ($Q_{30,10}$) in cubic feet per second, is the average minimum streamflow expectedfor 30 consecutive days once every 10 years.

Climatic year is a 12-month period from April 1 to March 31.

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

Flow-duration table, in cubic feet per second, includes the streamflow that was equaled or exceeded for indicated percentage of time.

Harmonic mean, in cubic feet per second, is the reciprocal of the arithmetic mean of the reciprocals of a set of streamflow values for a specific period of record (Spiegel, 1961).

Mean, in cubic feet per second, is the average flow for a stream during a specific period of record.

Median, in cubic feet per second, is the flow of a stream for which there are equal numbers greater than or less than flow occurrences during a specific period of record.

Selected References

Ehlke, M.H., and Reed, L.A., 1999, Comparison of methods for computing streamflow statistics for Pennsylvania streams: U.S. Geological Survey, Water Resources Investigations 99-4068, 80 p.

Flippo, H.N., Jr., 1982a, Technical manual for estimating low-flow characteristics of Pennsylvania streams: Pennsylvania Department of Environmental Resources, Water Resources Bulletin 15, 86 p.

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Spiegel, M.R., 1961, Schaum's Outline of Theory and Problems of Statistics: New York, McGraw-Hill Book Co., 359 p.

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf