Imminent Flood Analysis
Article 107(c)

Aquatic Resources Group Meeting – January 11, 2011

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Preliminary Results. Not Approved or Reviewed by any Party

Overview of Presentation

- Objectives of Study
- General Approach
- Models used in Study
- Analysis Results for December Post-IPP Period

Preliminary Results. Not Approved or Reviewed by any Party

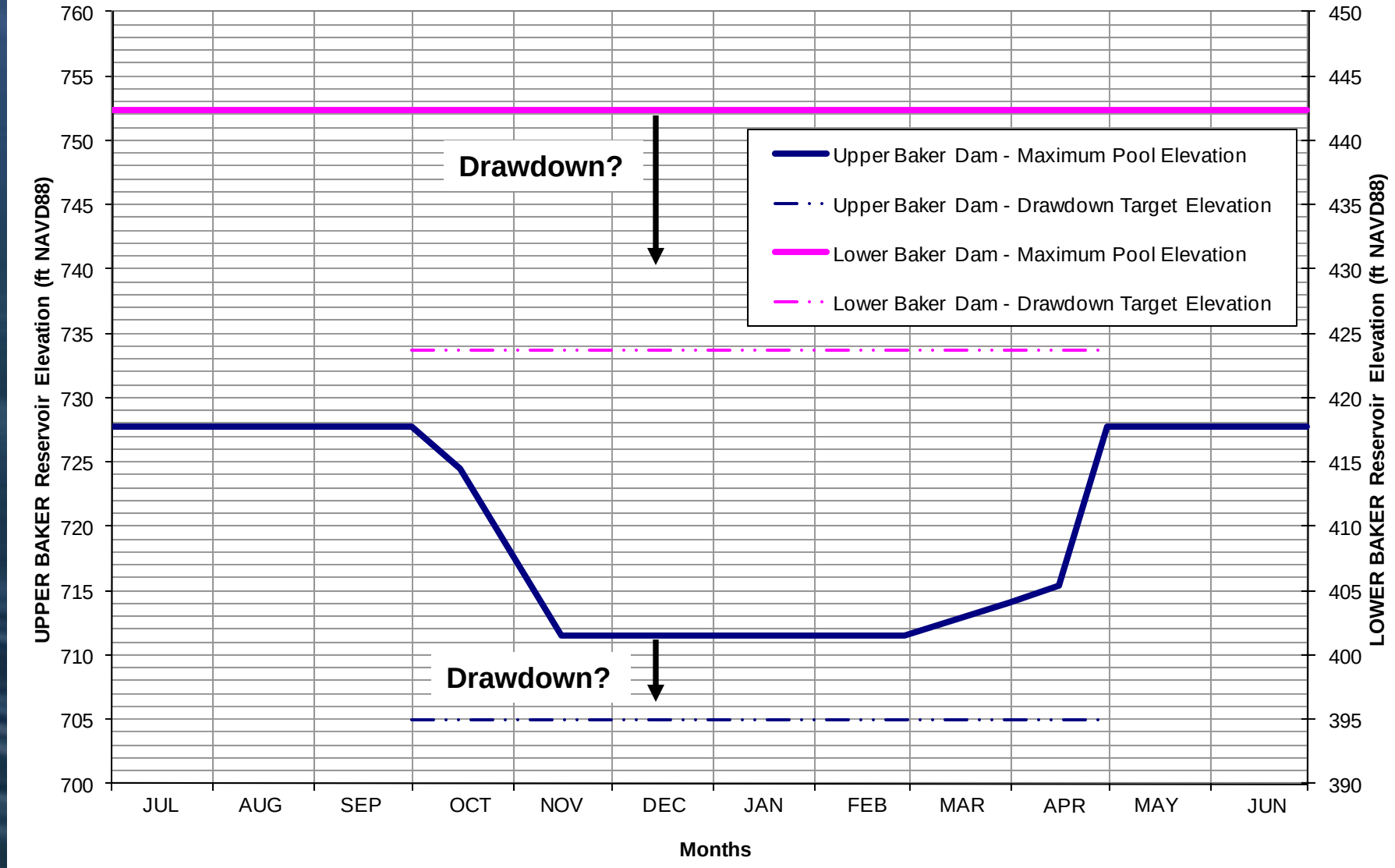
Study Objectives

- Evaluate ability to drawdown Baker Project
  - Drawdown days prior to forecasted flood event
  - Reservoir drawdown target elevations:
    - Baker Lake - 704.92 ft NAVD 88
    - Lake Shannon - 423.66 ft NAVD 88
  - Drawdown consistent with license articles 106 and 107
  - Drawdown associated with alternative operations

Study Objectives

- Evaluate flood benefits of evacuating additional flood control volume
  - Flood benefits = reduced peak flows on Skagit River
- Develop protocols for imminent flood drawdown

Preliminary Results. Not Approved or Reviewed by any Party



Upper and Lower Baker Dam Rule Curves for Post-IPP Conditions (Year 2013)

Preliminary Results. Not Approved or Reviewed by any Party

Study Objectives

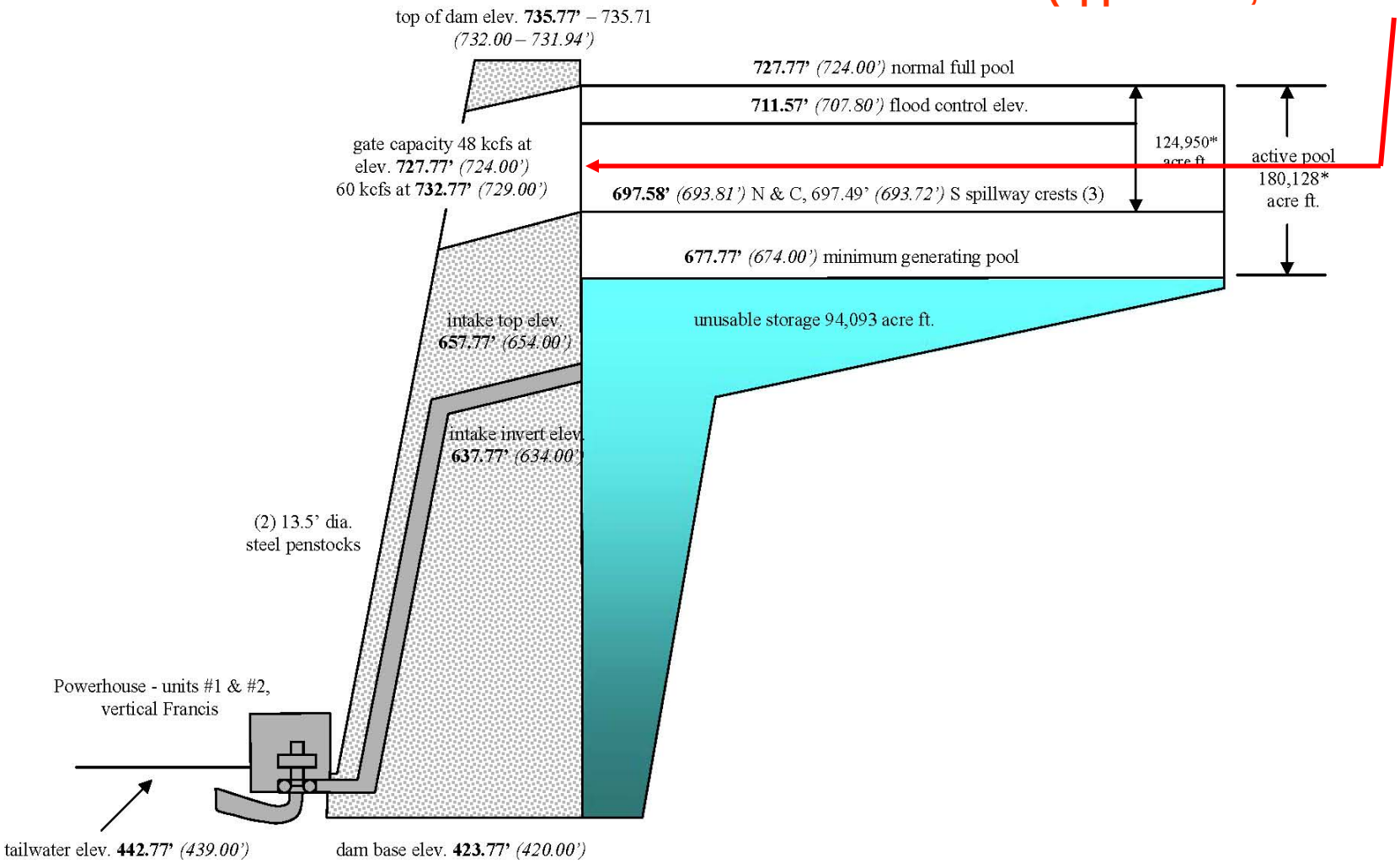
Other key questions that study will answer:

- Is there a threshold event for which imminent flood drawdown could moderate flood impacts ?
- Is the threshold event seasonally dependent ?
- Which NWS river forecast station(s) should be used to monitor for imminent flood ?

Target Drawdown Elevation
704.92 ft NAVD88
(approx 100,000 ac-ft)

Upper Baker Dam / Baker Lake

Section View - Not to Scale



NAVD 88 elevations *(NGVD 29 elev.)*
{1907 datum used thru 1947, then added 1.72' for NGVD 29, added another 3.77' to UB NAVD 88 ~ 2003}

Project Storage (acre ft.)	Upper	Lower	Combined
Total active	180,128*	116,770*	296,898*
Total above spillways	124,950*	29,426*	154,376*

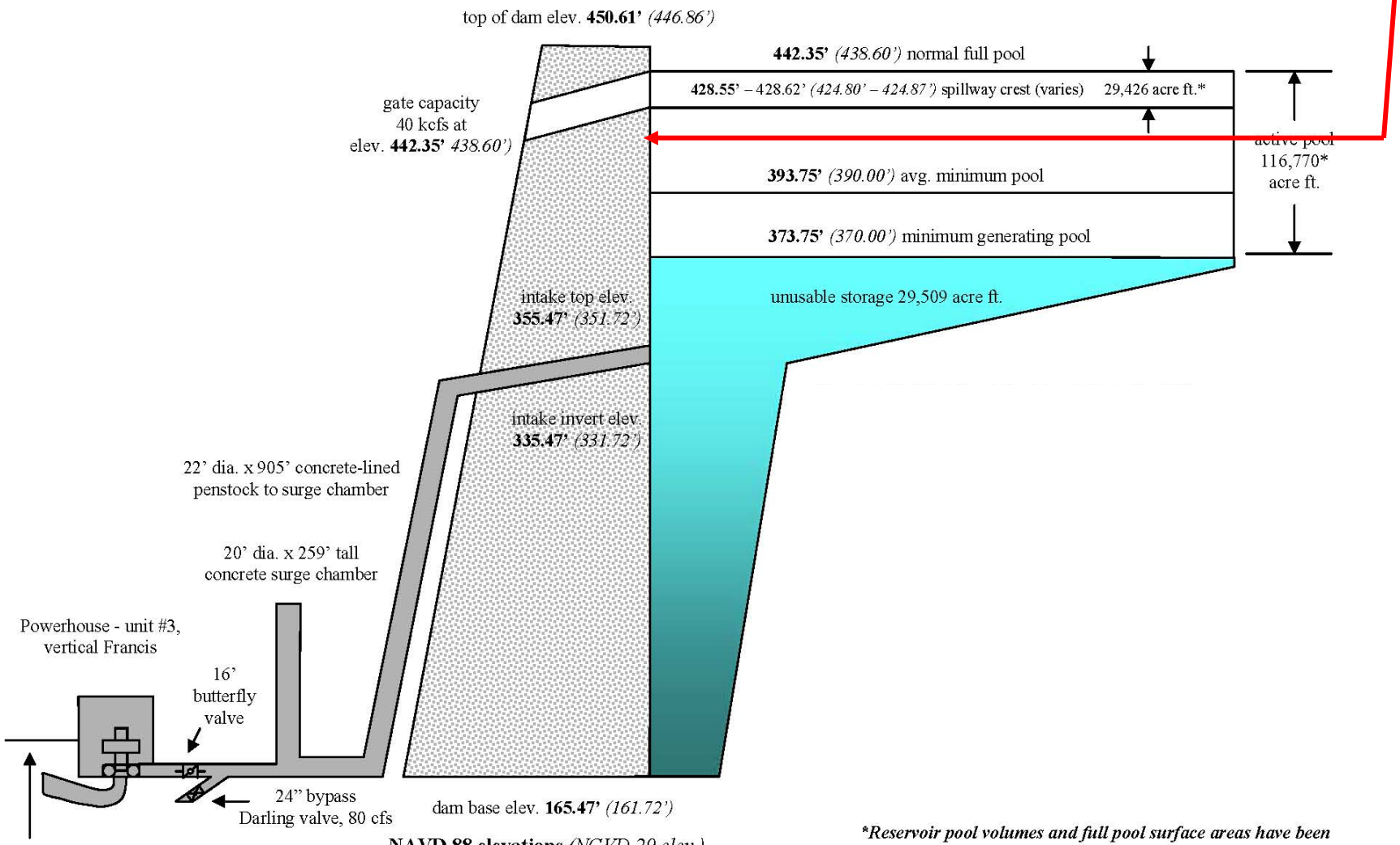
Filename: dams schematics 10/22/09, NV

Preliminary Results. Not Approved or Reviewed by any Party

Target Drawdown Elevation
423.66 ft NAVD88
(approx 39,000 ac-ft)

Lower Baker Dam / Lake Shannon

Section View - Not to Scale



NAVD 88 elevations *(NGVD 29 elev.)*
{1907 datum used thru 1947, then added 1.72' for NGVD 29, added another 3.75' to LB NAVD 88 ~ 2003}

***Reservoir pool volumes and full pool surface areas have been adjusted using reservoir storage-elevation relationships updated as of Sept. 26, 2003 (R2 master hydrology disk #2) based on 2001 survey data.**

Filename: dams schematics 10/22/09, NV

Preliminary Results. Not Approved or Reviewed by any Party

Approach - Preview

- Hydrology
- Analytical Periods
- Models
- Overview of Flood Operation of Baker Project

Preliminary Results. Not Approved or Reviewed by any Party

Approach - Hydrology

- Analyses use synthesized, balanced Skagit River inflow flood hydrographs
  - Developed for Skagit River GI Study
  - Local inflows to Skagit River (10 inflow locations)
  - 2-yr through 500-yr return periods
- Drawdown protocols will be based on results of analysis
- Historical hydrographs will then be used to test or refine protocols

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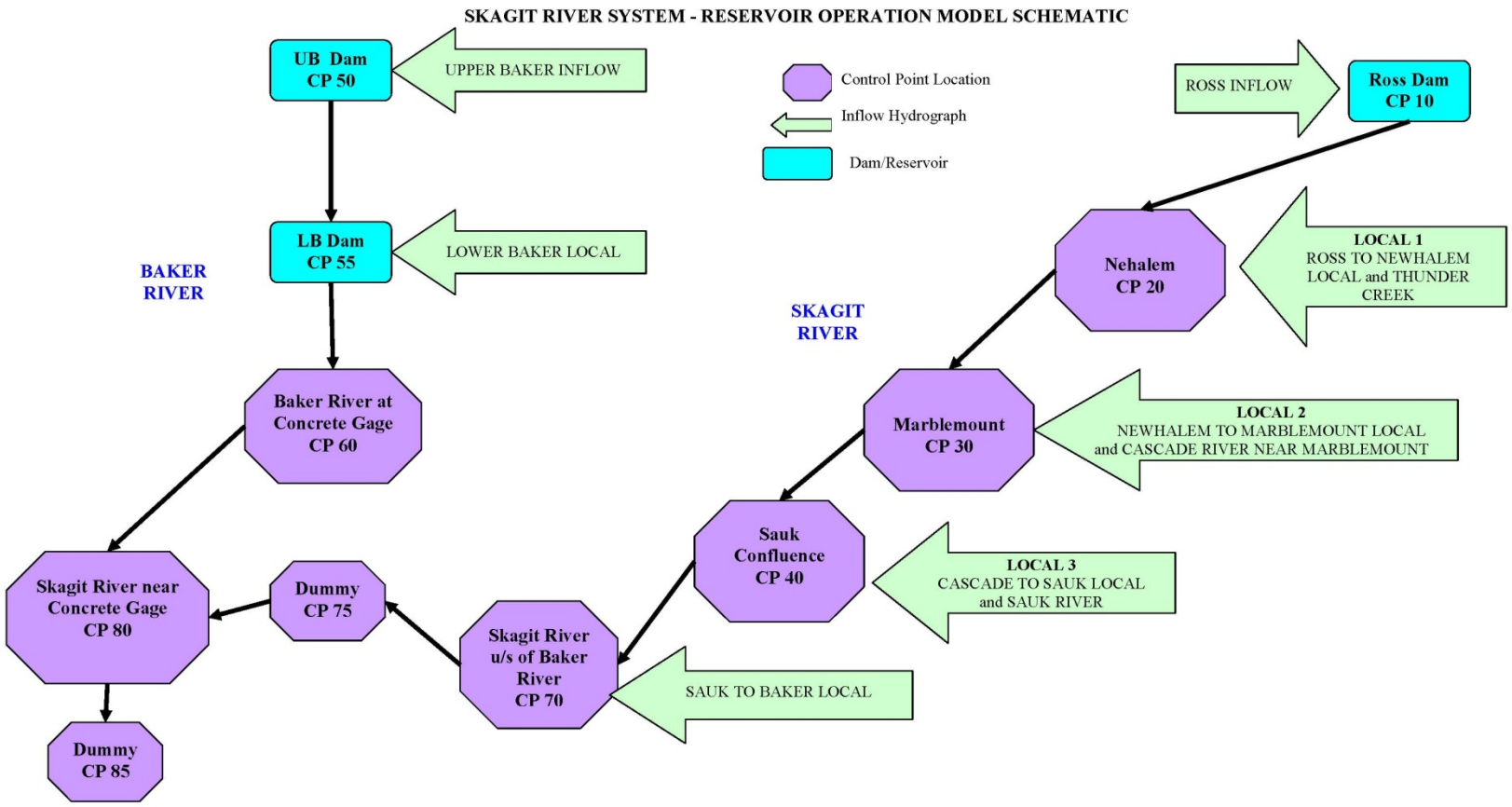
Inflow Locations



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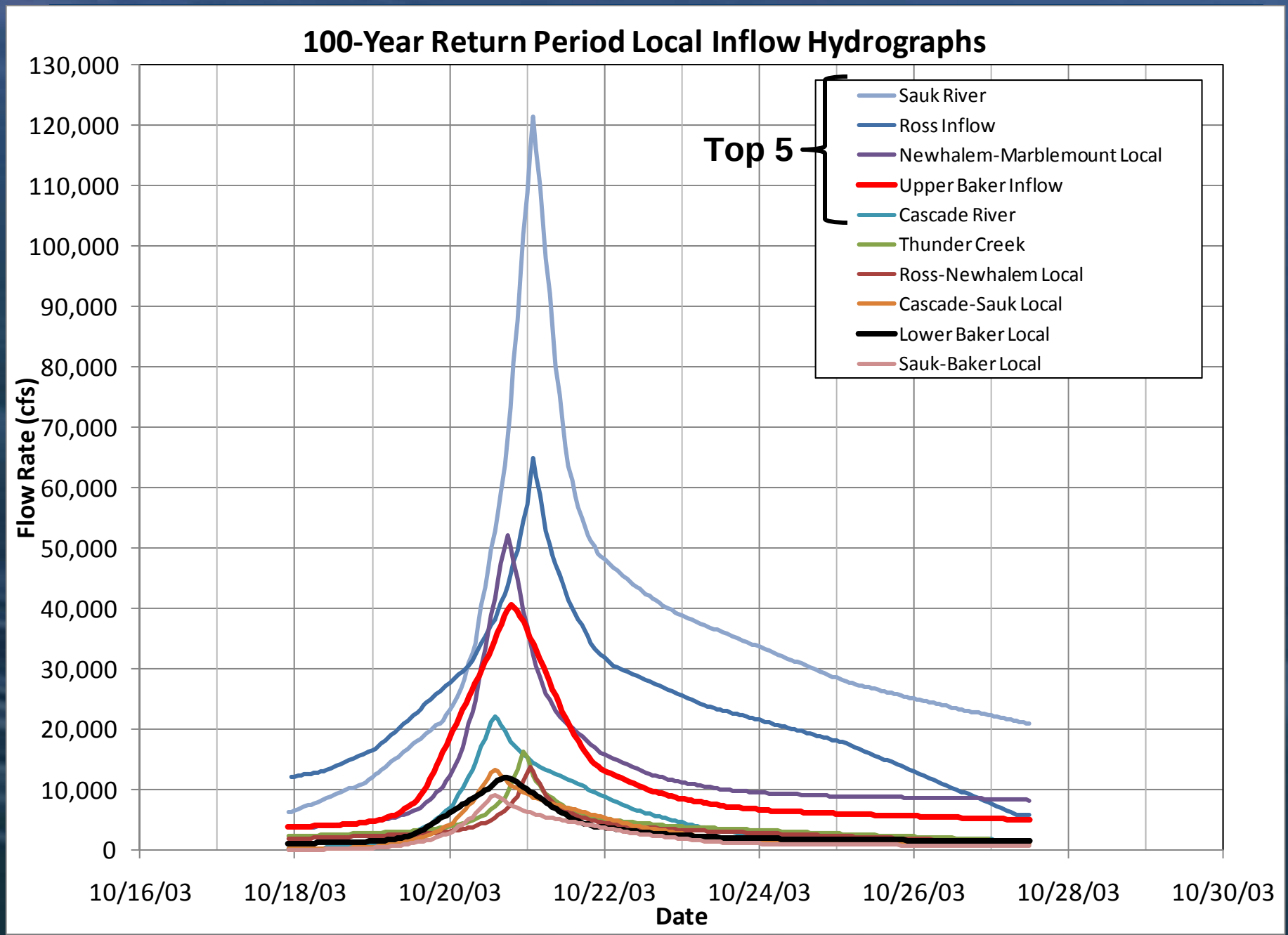

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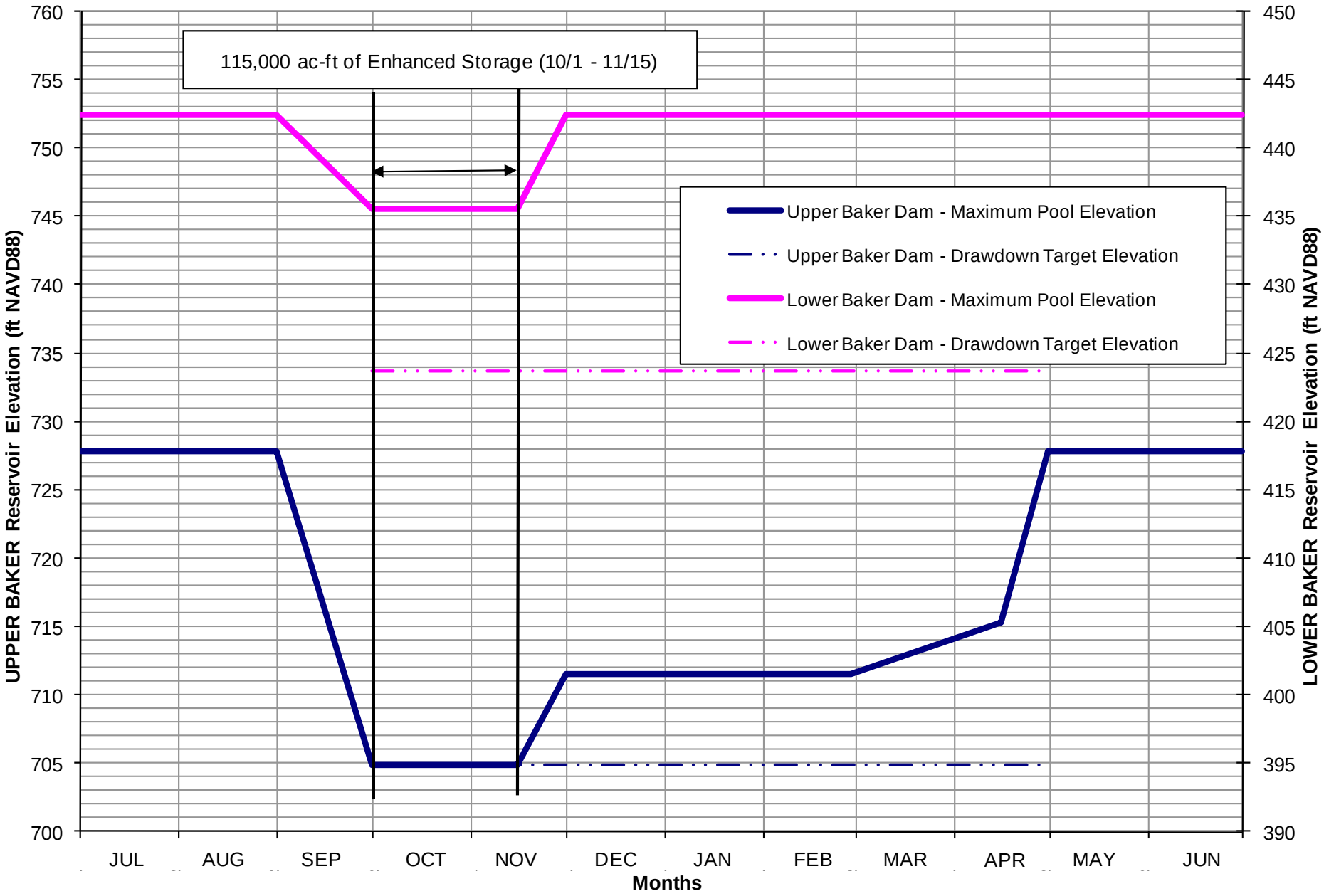
Analytical Periods

- Flood season subdivided into analytical periods

- Necessary because of the number of variables:
  - UB reservoir elevation at start of drawdown *
  - LB reservoir elevation at start of drawdown *
  - Coincident flow conditions during drawdown *
  - Constraints on LB releases during drawdown *
  - Duration of drawdown (in days)
  - Magnitude of the imminent flood event

* Variable that is seasonally (monthly) dependent

- IPP and Post-IPP Operation Plans



Upper and Lower Baker Dam Rule Curves for IPP

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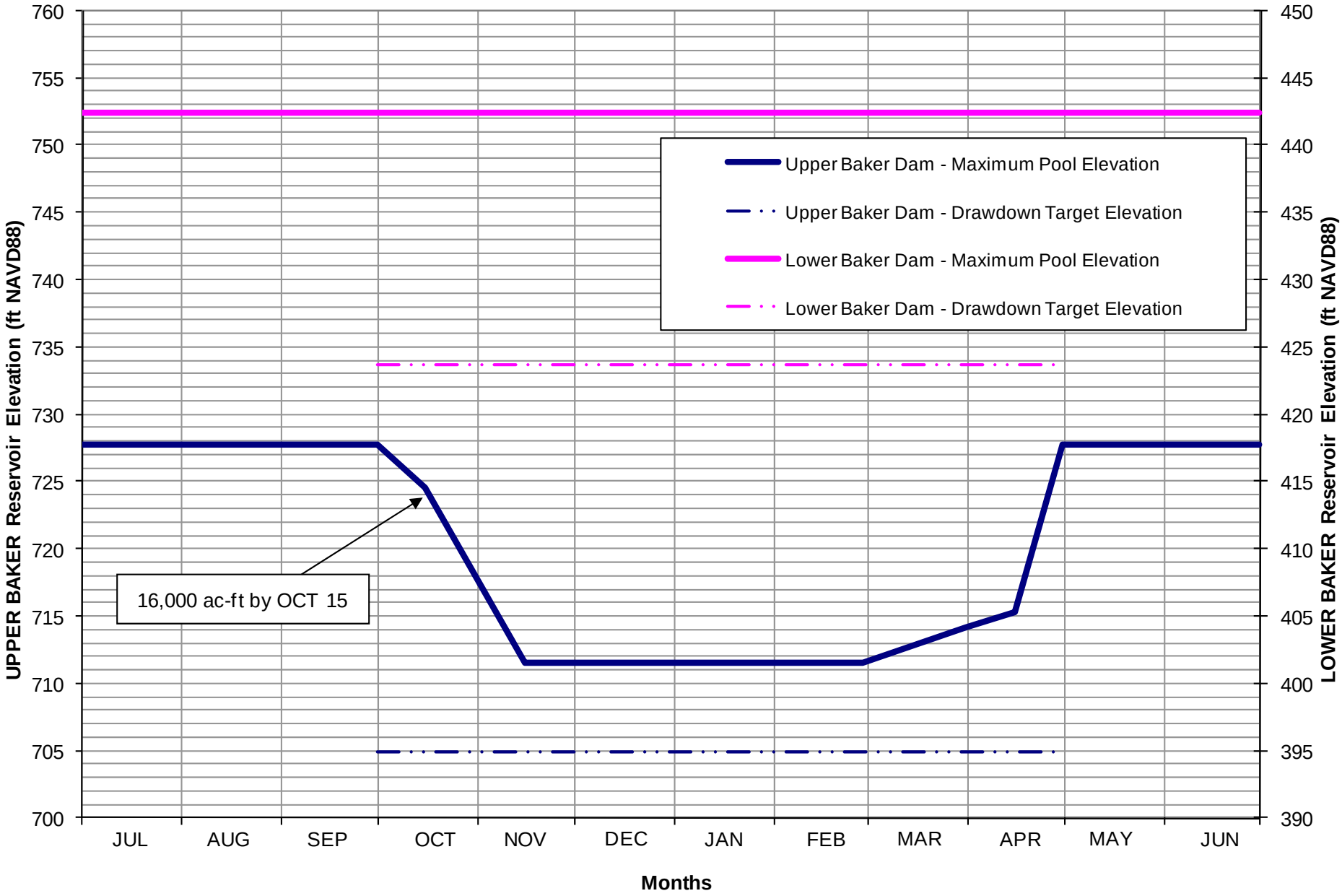

Upper and Lower Baker Dam Rule Curves for Post-IPP

Preliminary Results. Not Approved or Reviewed by any Party

Analytical Periods - IPP

Definition of Analytical Periods and Operational Differentiators for Imminent Flood Drawdown Analysis
INTERIM PROTECTION PLAN (IPP)

Period	Upper Baker Dam		Lower Baker Dam		Ross Dam		Constraints on Lower Baker Outflows
	Maximum Allowable Reservoir Elevation (ft NAVD88)	Available Flood Control Volume (ac-ft)	Maximum Allowable Reservoir Elevation (ft NAVD88)	Available Flood Control Volume (ac-ft)	Maximum Allowable Reservoir Elevation (ft NGVD29)	Available Flood Control Volume (ac-ft)	
OCT 1 – 15	704.92	100,000	435.54	15,000	1601.72	10,000	3,200 cfs max flow; 3 hrs/day
OCT 16 – 31	704.92	100,000	435.54	15,000	1599.95	31,500	3,200 cfs max flow; 24 hrs/day
NOV 1 – 15	704.92	100,000	435.54	15,000	1598.18	50,500	3,200 cfs max flow; 24 hrs/day
NOV 16 – 30	708.25	87,295	438.95	7,619	1594.42	93,700	3,200 cfs max flow; 24 hrs/day
DEC 1 – 31	711.57	74,000	442.35	0	1592.10	120,000	3,200 cfs max flow; 24 hrs/day
JAN 1- 31	711.57	74,000	442.35	0	1592.10	120,000	No constraints; **no analysis req'd**
FEB 1 -28	711.57	74,000	442.35	0	1592.10	120,000	No constraints; **no analysis req'd**
MAR 1 - 15	712.23	71,225	442.35	0	1592.10	120,000	Not in flood season; **no analysis req'd**
MAR 16 - 31	713.45	66,111	442.35	0	1602.50	0	Not in flood season; **no analysis req'd**
APR 1 – 15	714.77	60,487	442.35	0	1602.50	0	Not in flood season; **no analysis req'd**
APR 16 - 30	721.97	28,055	442.35	0	1602.50	0	Not in flood season; **no analysis req'd**

Analytical Periods – Post-IPP

Definition of Analytical Periods and Operational Differentiators for Imminent Flood Drawdown Analysis
POST INTERIM PROTECTION PLAN (POST IPP)

Period	Upper Baker Dam		Lower Baker Dam		Ross Dam		Constraints on Lower Baker Outflows
	Maximum Allowable Reservoir Elevation (ft NAVD88)	Available Flood Control Volume (ac-ft)	Maximum Allowable Reservoir Elevation (ft NAVD88)	Available Flood Control Volume (ac-ft)	Maximum Allowable Reservoir Elevation (ft NGVD29)	Available Flood Control Volume (ac-ft)	
OCT 1 – 20	725.59	10,732	442.35	0	1601.39	13,100	3,200 cfs maximum flow
OCT 21 – 31	719.91	37,623	442.35	0	1599.73	32,300	3,600 cfs maximum flow
NOV 1 – 15	714.49	61,687	442.35	0	1598.18	50,500	3,600 cfs maximum flow
NOV 16 – 30	711.57	73,952	442.35	0	1594.42	93,700	3,600 cfs maximum flow
DEC 1 – 31	711.57	73,952	442.35	0	1592.10	120,000	3,600 cfs maximum flow
JAN 1- 31	711.57	73,952	442.35	0	1592.10	120,000	5,600 cfs maximum powerhouse flow plus spillway flow; **no analysis req'd**
FEB 1 -28	711.57	73,952	442.35	0	1592.10	120,000	5,600 cfs maximum powerhouse flow plus spillway flow; **no analysis req'd**
MAR 1 - 15	712.23	71,225	442.35	0	1592.10	120,000	Outside of flood season; **no analysis req'd**
MAR 16 - 31	713.45	66,111	442.35	0	1602.50	0	Outside of flood season; **no analysis req'd**
APR 1 – 15	714.77	60,487	442.35	0	1602.50	0	Outside of flood season; **no analysis req'd**
APR 16 - 30	721.97	28,055	442.35	0	1602.50	0	Outside of flood season; **no analysis req'd**

Models

- Drawdown Model
  - Excel-based model, hourly time step
  - Quantifies reservoir evacuation during days prior to flood
- Reservoir Operation Model
  - USACE HEC-5 Model
  - Simulates reservoir operation during flood
  - Uses starting reservoir elevation from drawdown model
- Both models have been verified

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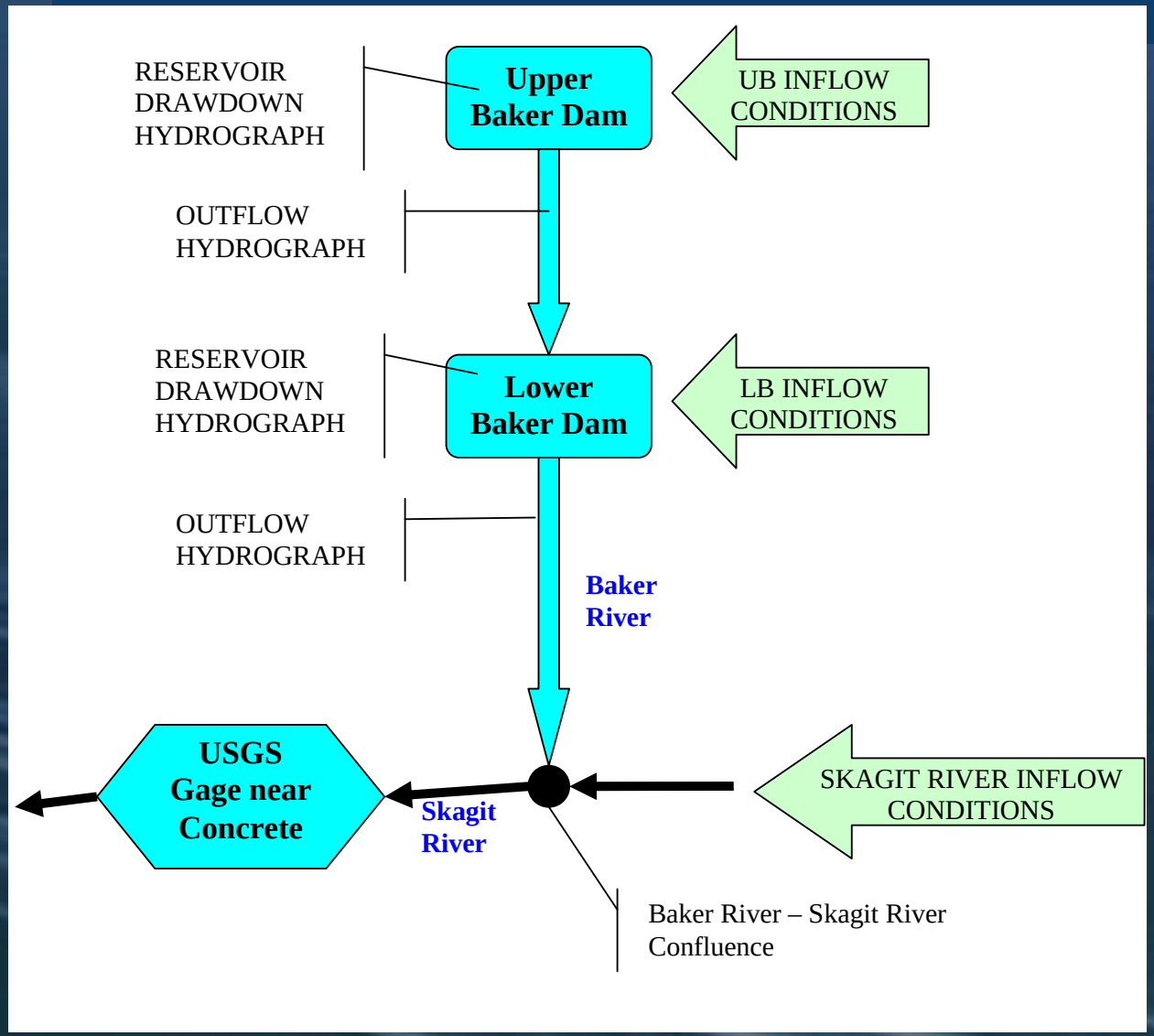
Drawdown Model Schematic

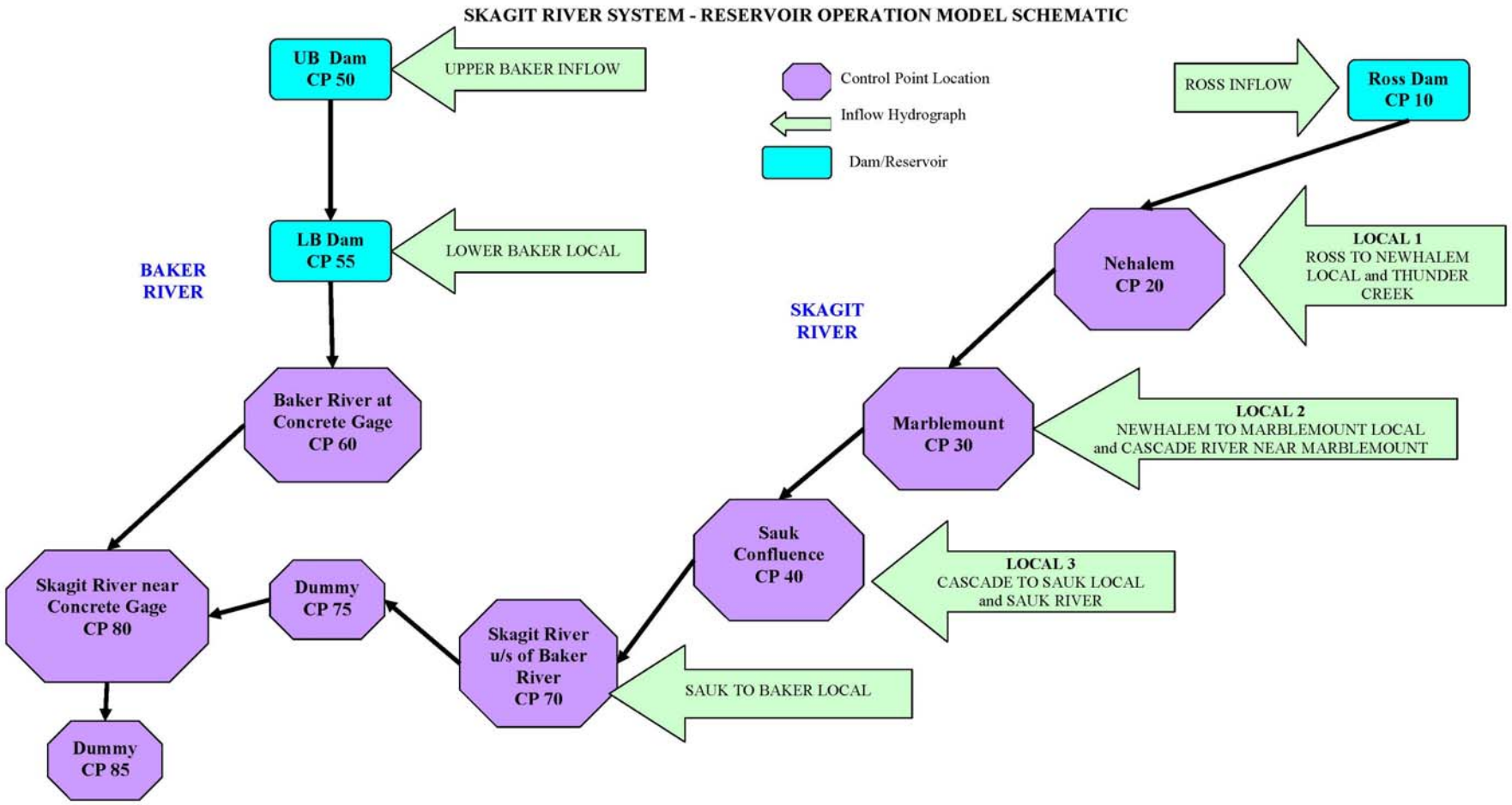


"Model Input"

"Model Output"

Preliminary Results. Not Approved or Reviewed by any Party

Reservoir Operation Model Schematic



Approach

- How will imminent drawdown at Baker River Project reduce Skagit River peak flows?
- Different because of how the two reservoirs are managed during floods
  - Upper Baker Dam – Operated for flood control by USACE
  - Lower Baker Dam – Not operated by USACE
- Theoretical operation vs. actual operation

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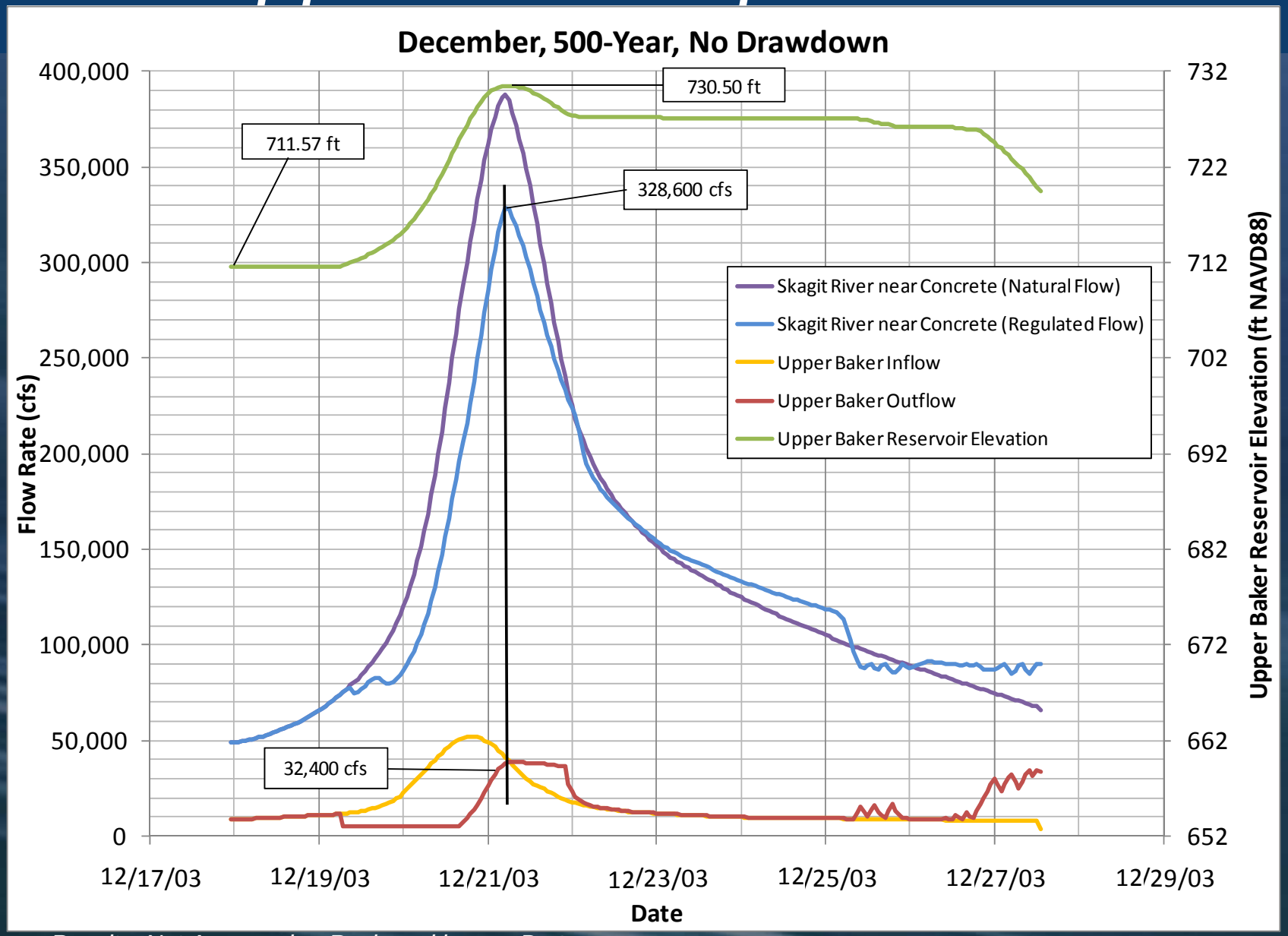
Upper Baker Operations



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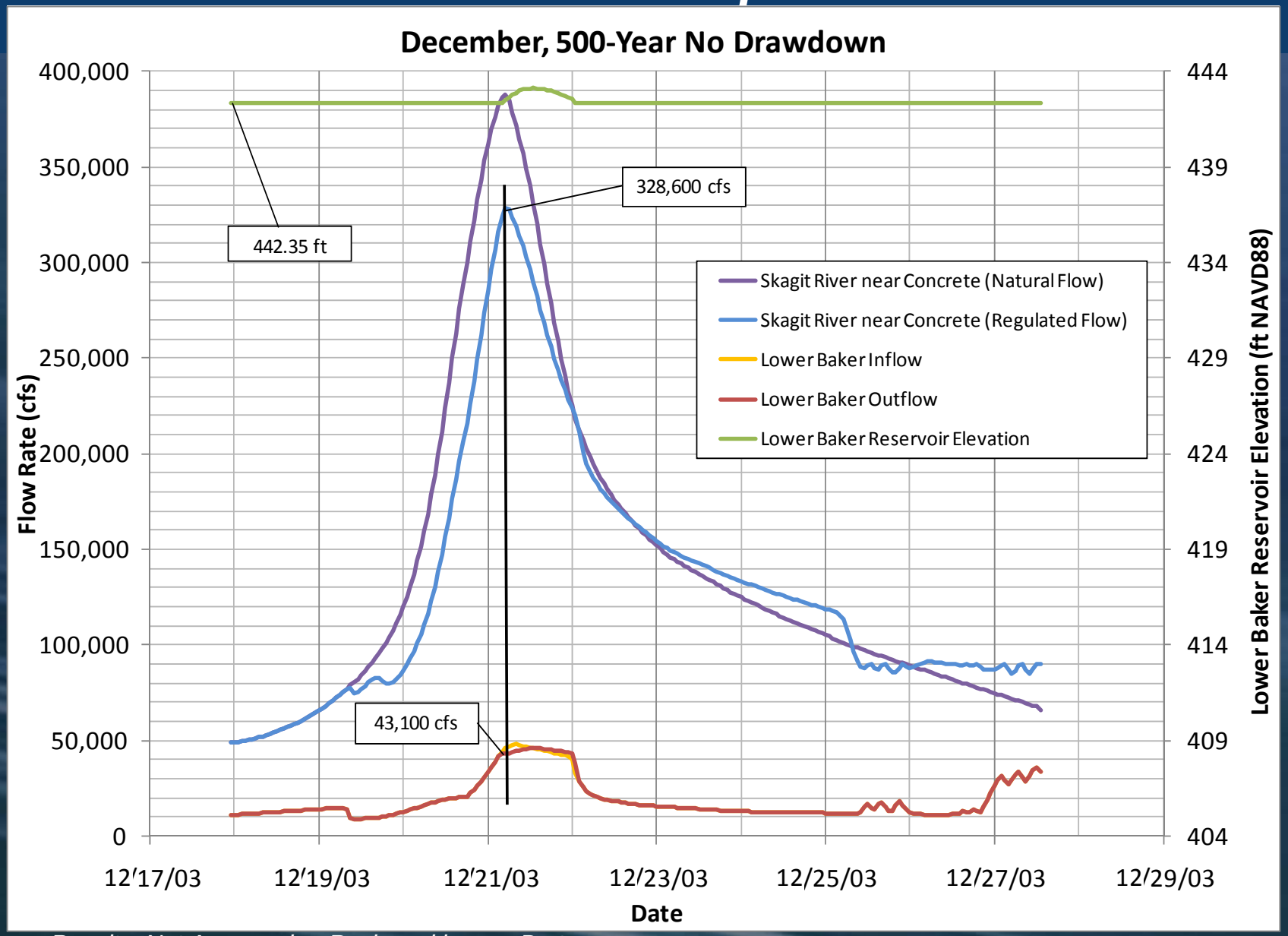
Lower Baker Operations



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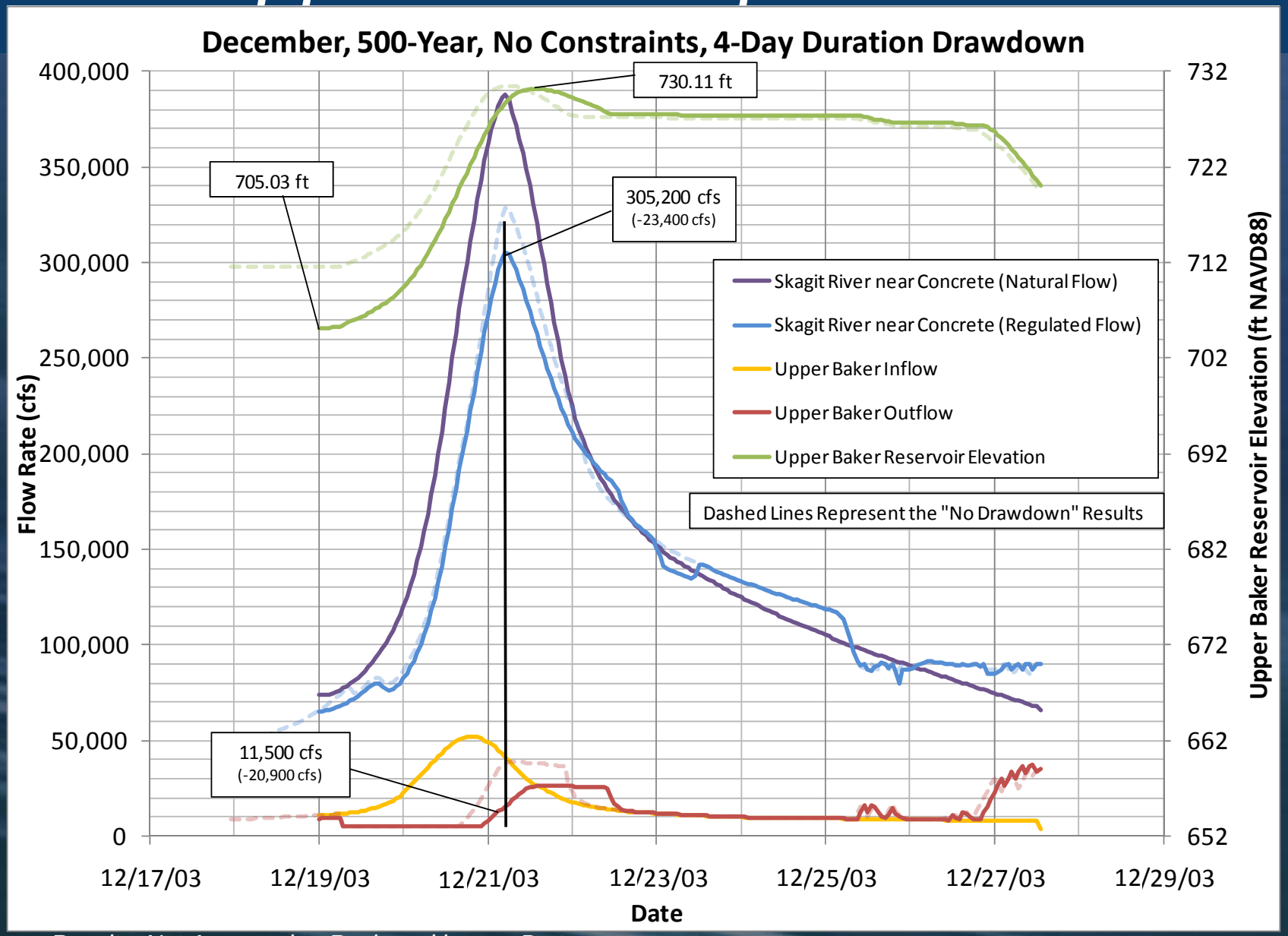
Upper Baker Operations



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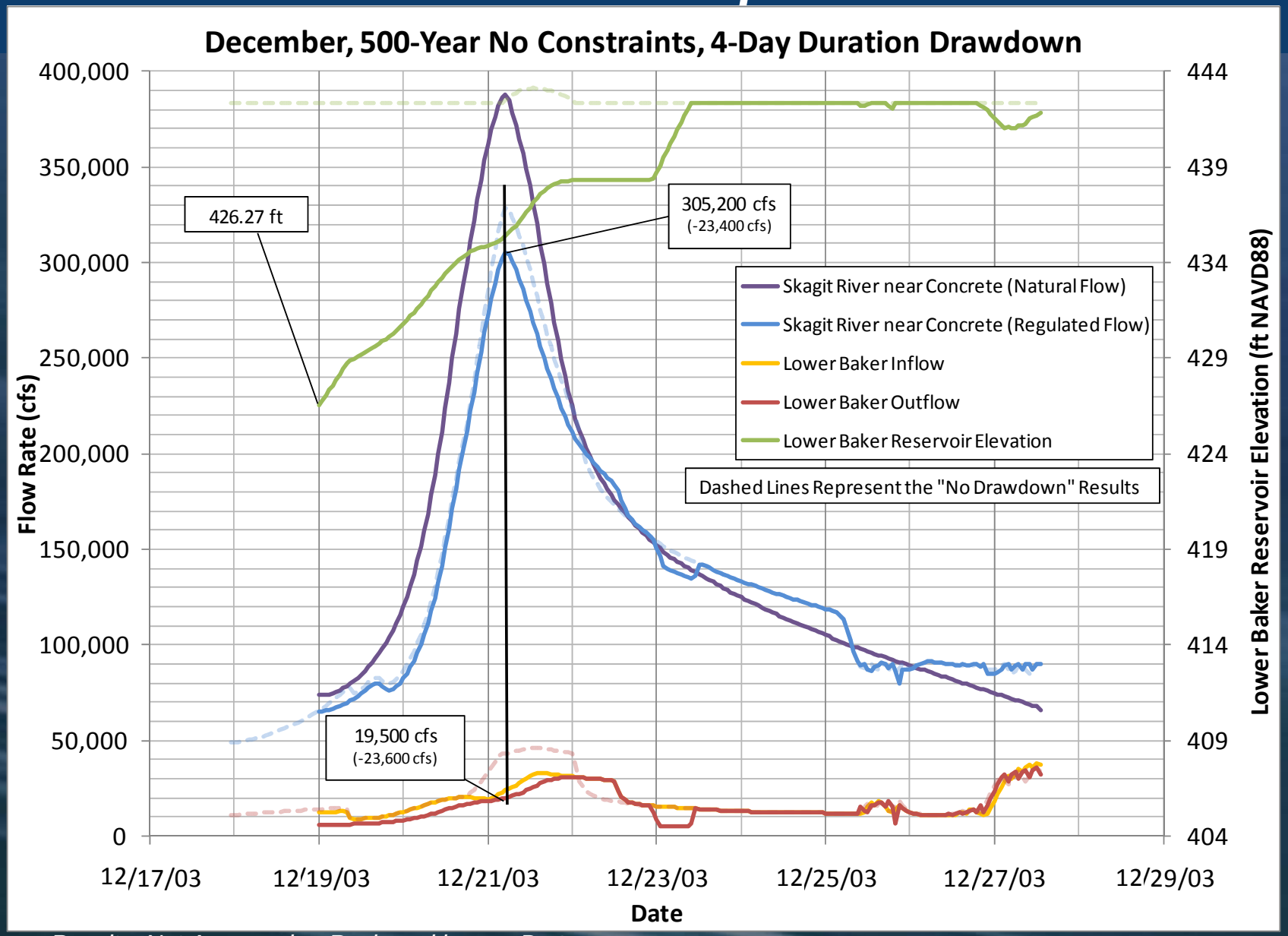
Lower Baker Operations



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Procedure

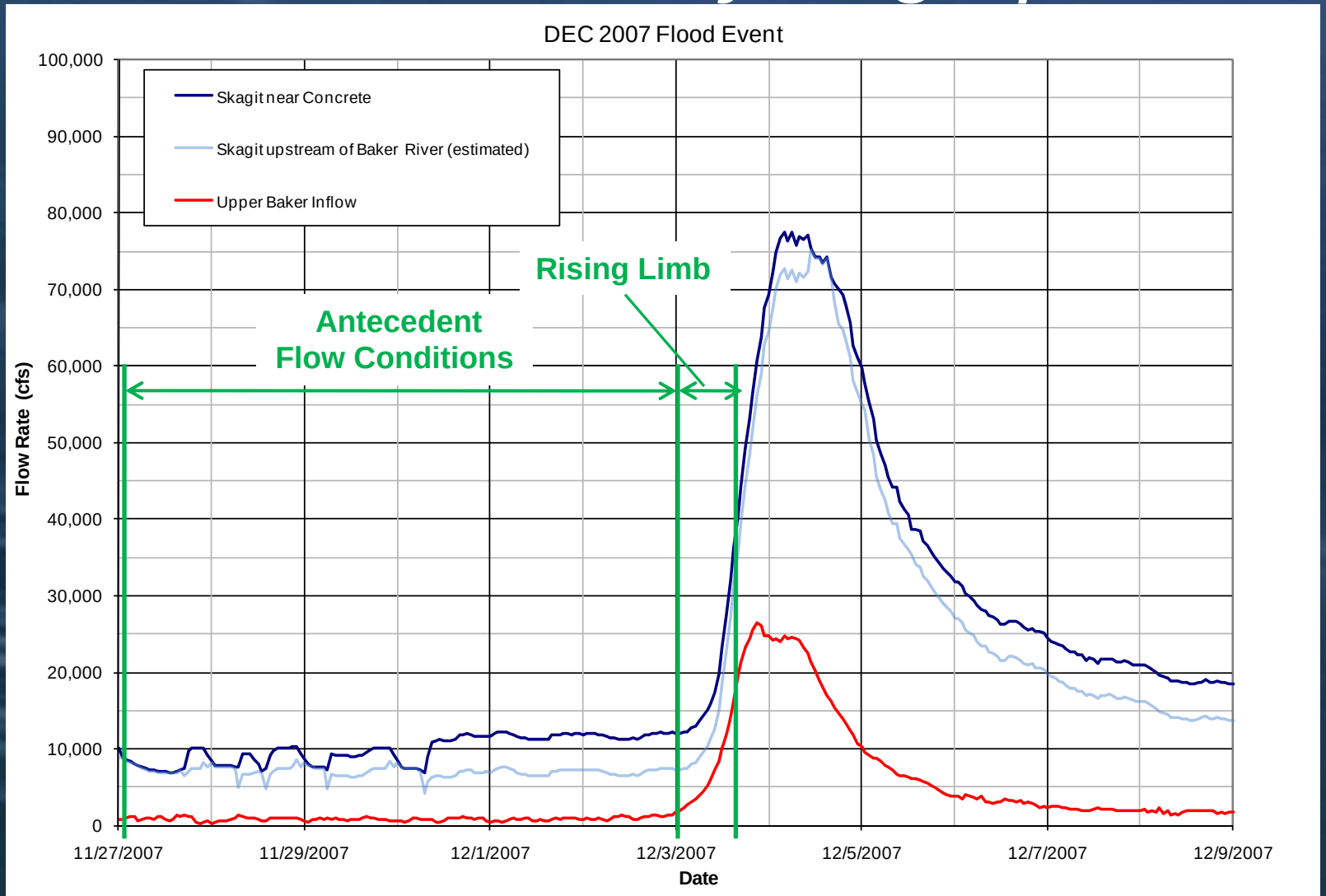
For each analytical period:

- Develop inflow hydrographs ahead of flood event for the drawdown model
- Conduct drawdown analysis
- Conduct reservoir operation analysis

Procedure - Drawdown Hydrographs

- Hydrologic conditions during days prior to flood
- Drawdown ends when Seattle District USACE takes over operation of Upper Baker Dam
- Drawdown hydrograph comprised of two “parts”:
  - Antecedent flow conditions
    - Constant
    - Dry, Average and Wet Conditions
  - Initial part of rising limb of flood hydrograph

Procedure - Drawdown Hydrographs



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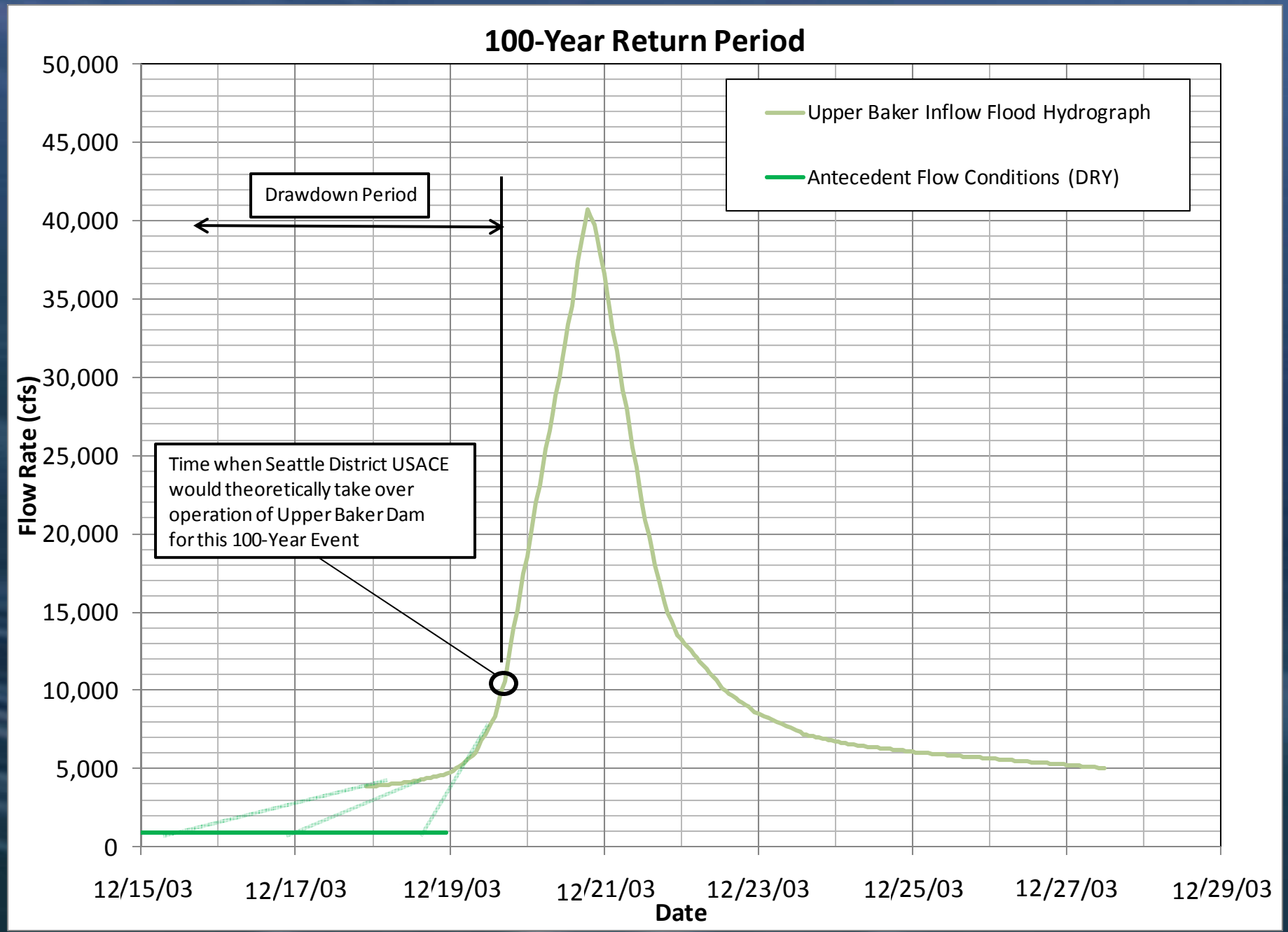

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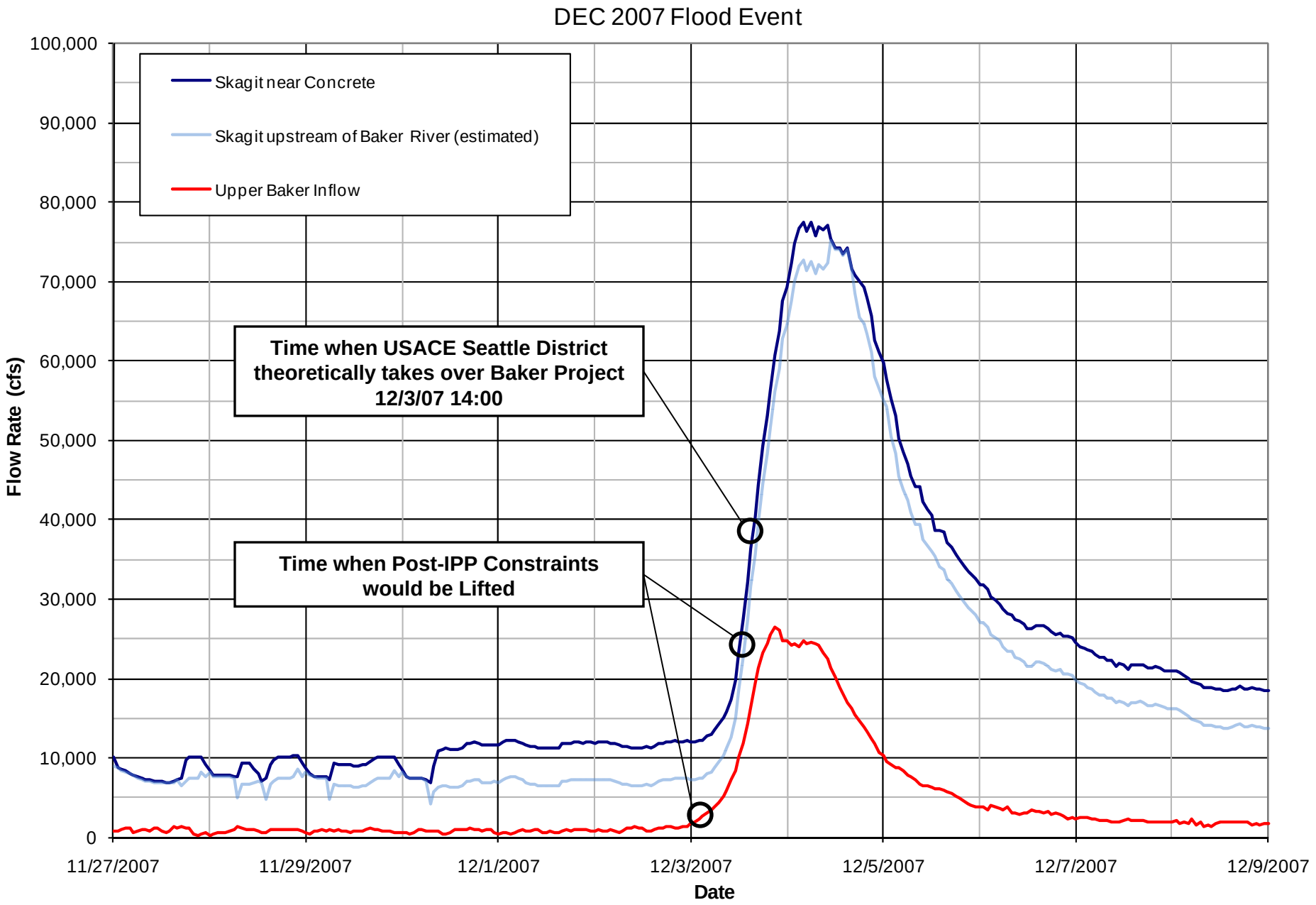
Procedure - Drawdown Hydrographs

- Need defensible method to “connect” antecedent flow to the flood hydrograph

- Used historical flood hydrographs as basis
  - Evaluated the rising limbs of the hydrographs
  - Quantified the number of hours when conditions would have allowed for unconstrained releases from LB



Preliminary Results. Not Approved or Reviewed by any Party

Flood Event	Duration when Post-IPP Constraints would have been Lifted (hours)			Skagit River near Concrete Regulated Peak Flow
	Based on Skagit River Flow	Based on Upper Baker Inflow	Controlling Value	
NOV 89	8	18	18	101,000
NOV 90(1)	0	3	3	149,000
NOV 90(2)	47	14	47	146,000
NOV 95	131	121	131	159,000
OCT 03(1)	0	13	13	93,100
NOV06	48	76	76	145,000
DEC07	0	10	10	77,500
NOV08	0	8	8	66,100
JAN09	15	22	22	62,500
Average w/o two High Outliers =			**17**	

CONCLUSION: The number of hours when constraints would be lifted during imminent flood drawdown is not a function of the magnitude of the impending flood event.

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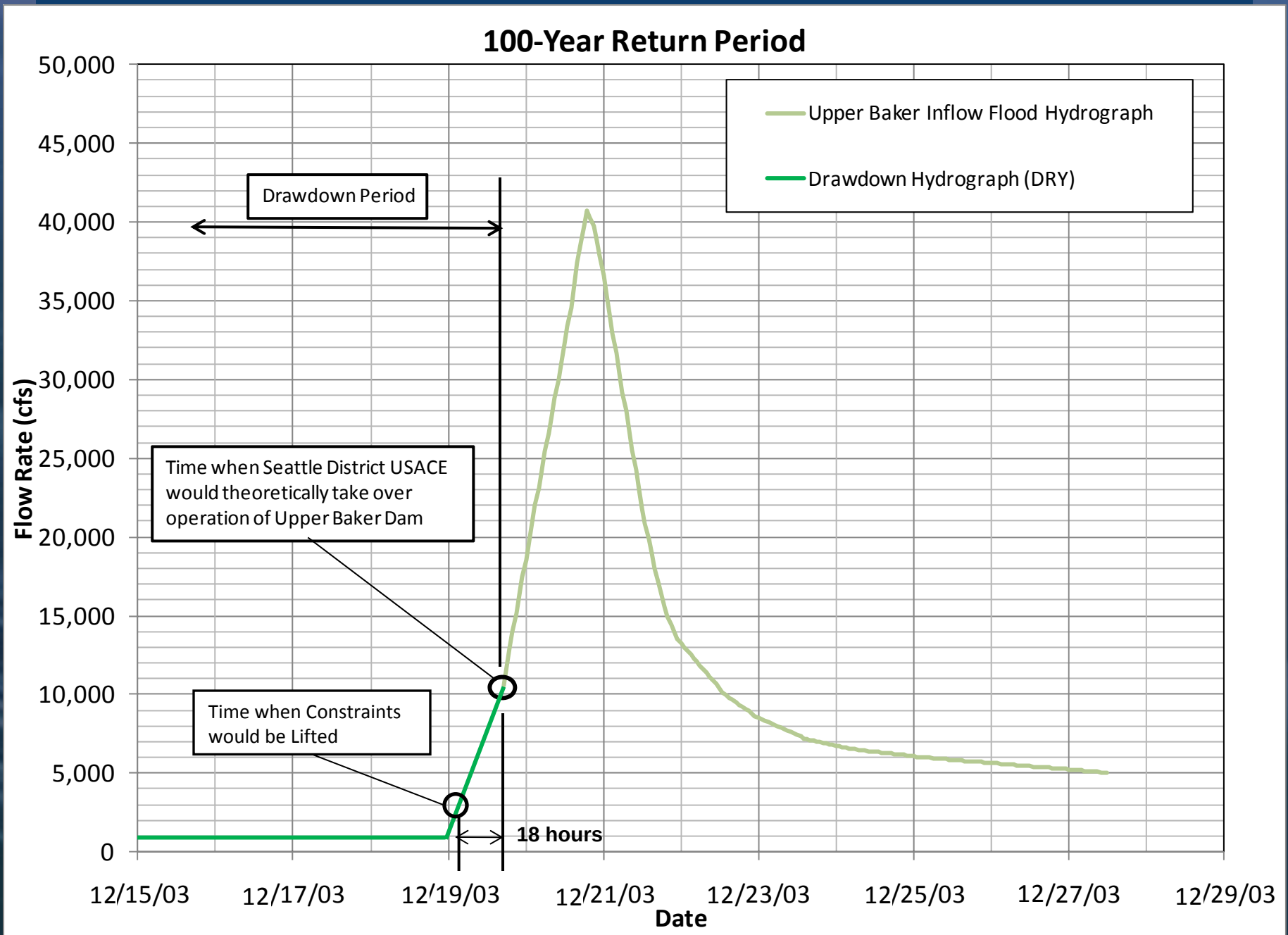

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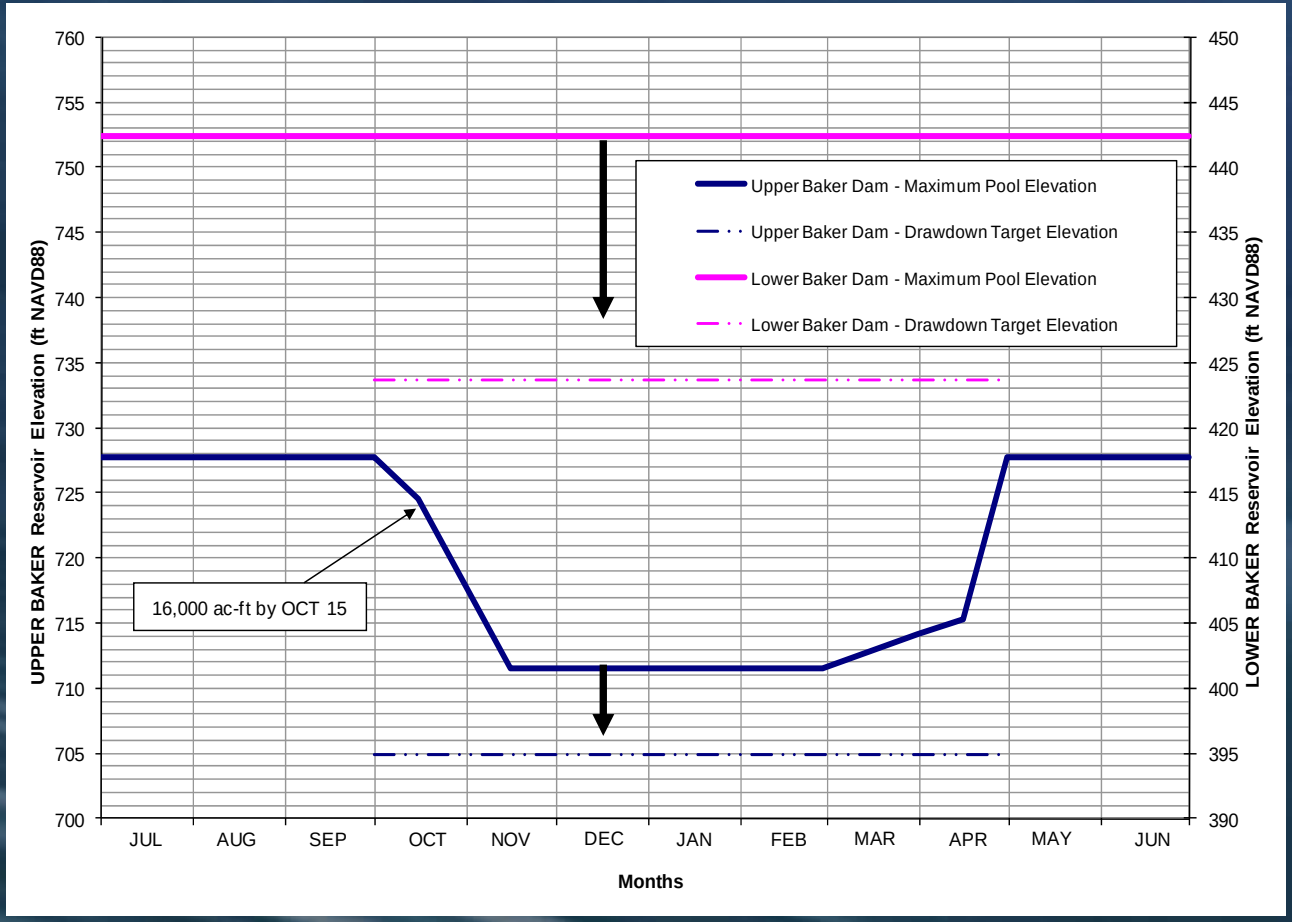
Procedure - Drawdown Hydrographs

- Summary
  - Drawdown hydrographs developed for three locations:
    - Upper Baker Inflow
    - Lower Baker Inflow
    - Skagit River u/s of Baker River
  - Drawdown hydrographs developed for:
    - 2-yr through 500-yr return periods and
    - Three antecedent flow conditions (DRY, AVG, WET)
  - Drawdown hydrographs characterized as:
    - Period of constant inflow
    - Initial rising limb of flood hydrograph
    - 18 hour period when LB release constraints would be lifted due to hydrologic conditions

Procedure

- Present preliminary results of analysis conducted for:
  - December
  - Post-IPP

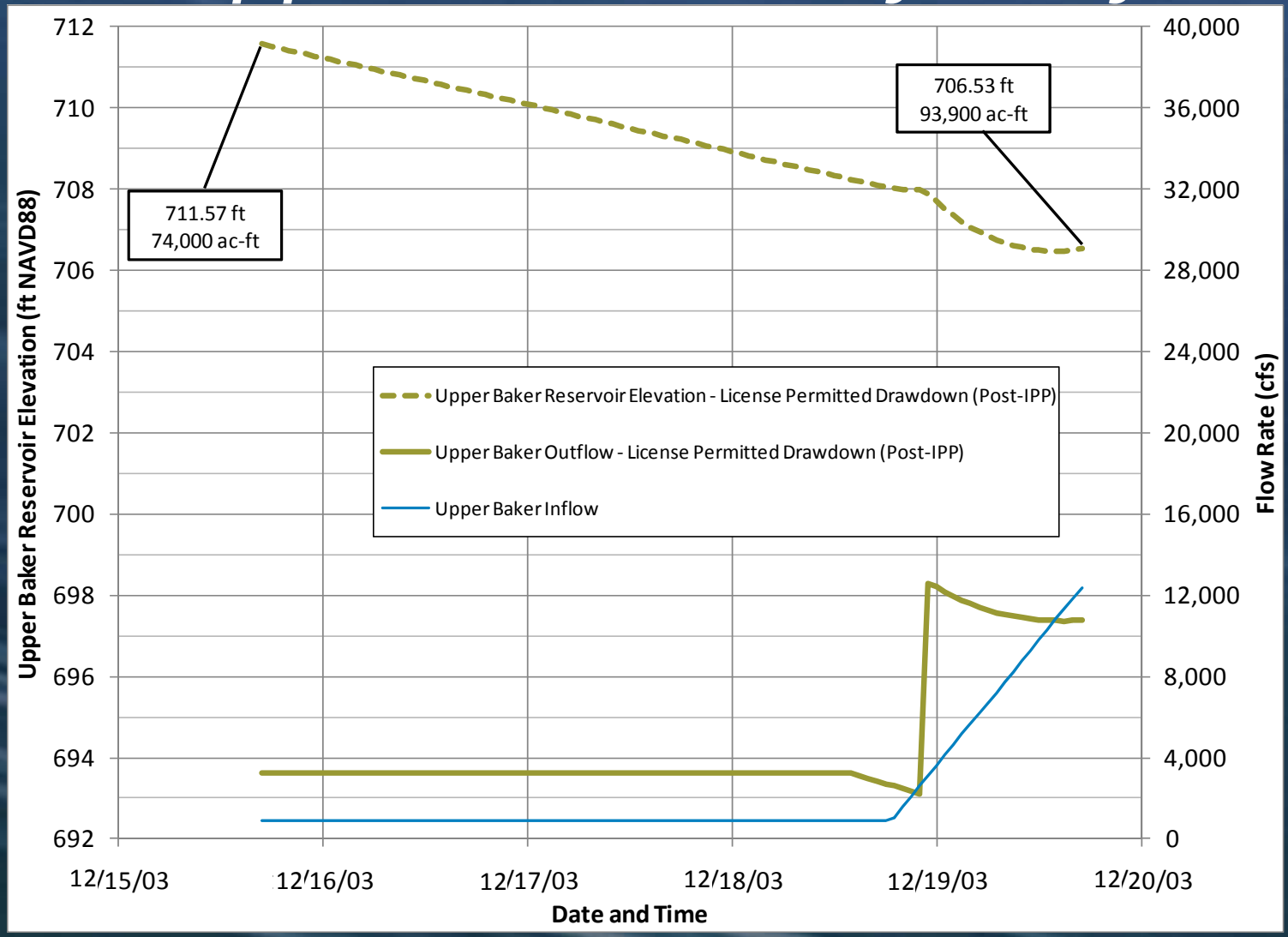


Preliminary Results. Not Approved or Reviewed by any Party

Procedure - Drawdown Analysis

- Conducted Drawdown Analysis for:
  - Wet, Average and Dry antecedent conditions (3)
  - 5-yr through 500-yr return periods (8)
- License Constraints vs. No Constraints (2)
- Starting Reservoir Elevations for all runs
  - Upper Baker - 711.57 ft NAVD88
  - Lower Baker - 442.35 ft NAVD88
- Drawdown Duration for the Analysis = 4 days

Drawdown Analysis Results
Upper Baker 100-yr, Dry



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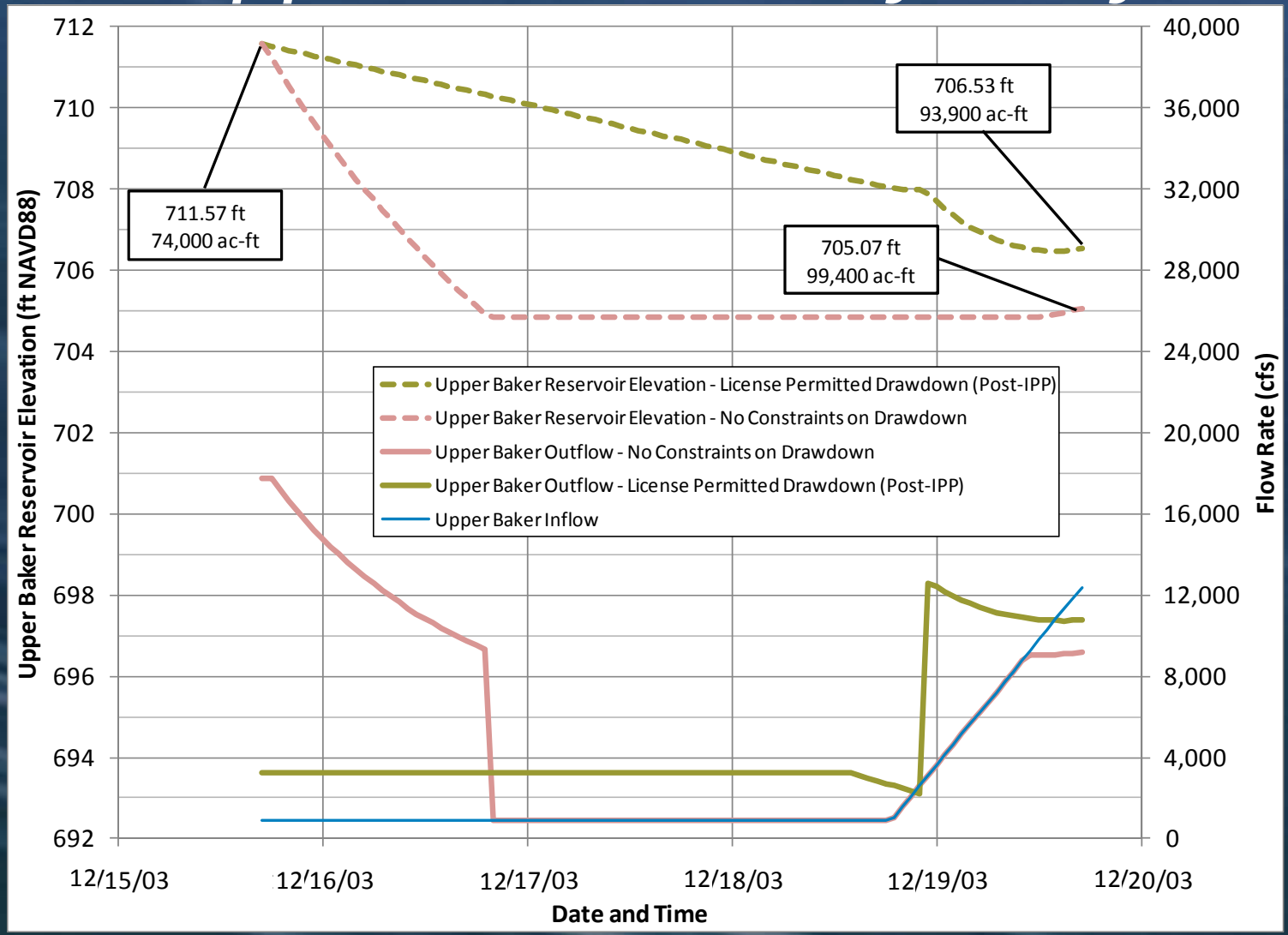
Drawdown Analysis Results
Upper Baker 100-yr, Dry



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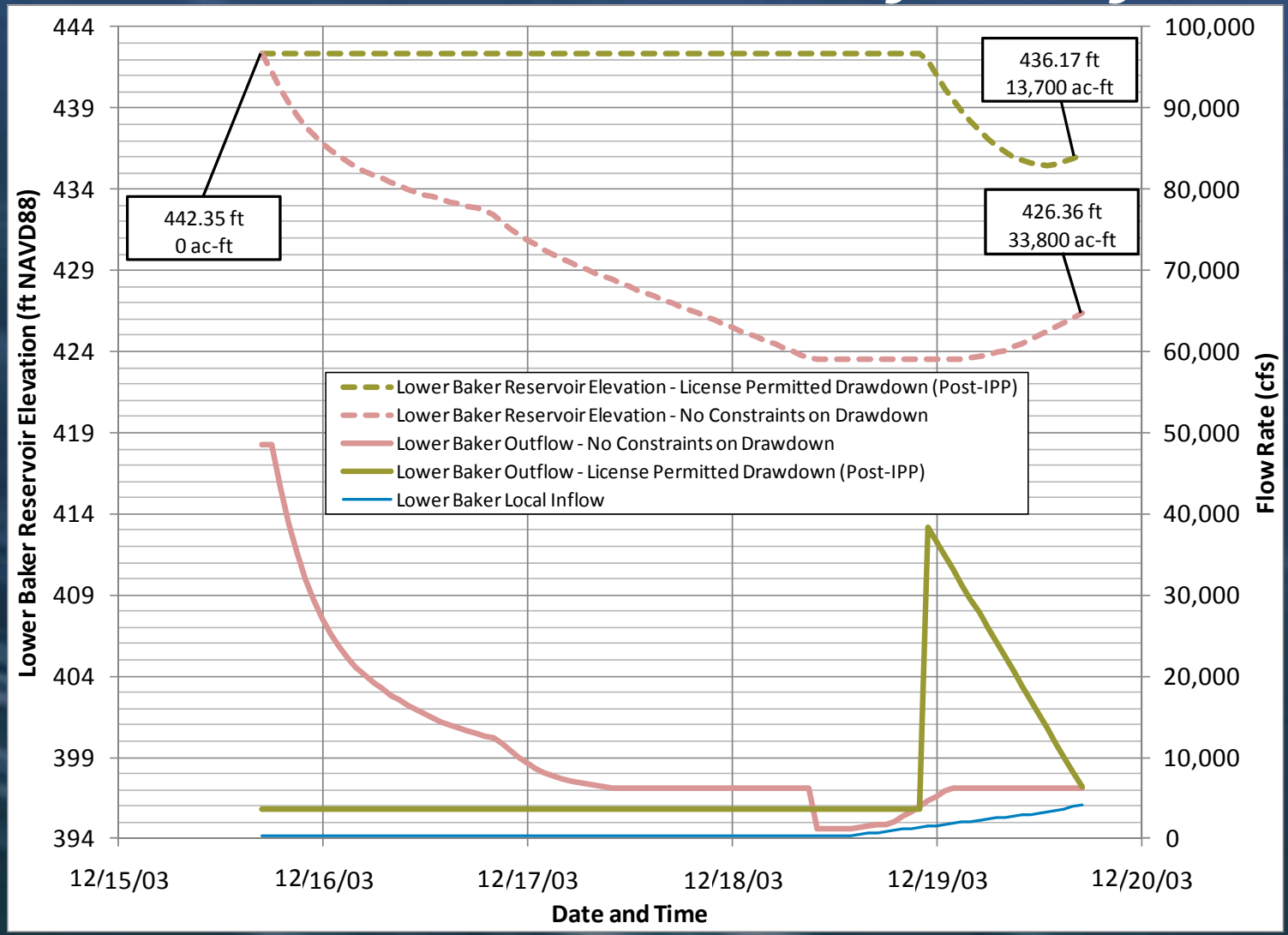
Drawdown Analysis Results
Lower Baker 100-yr, Dry



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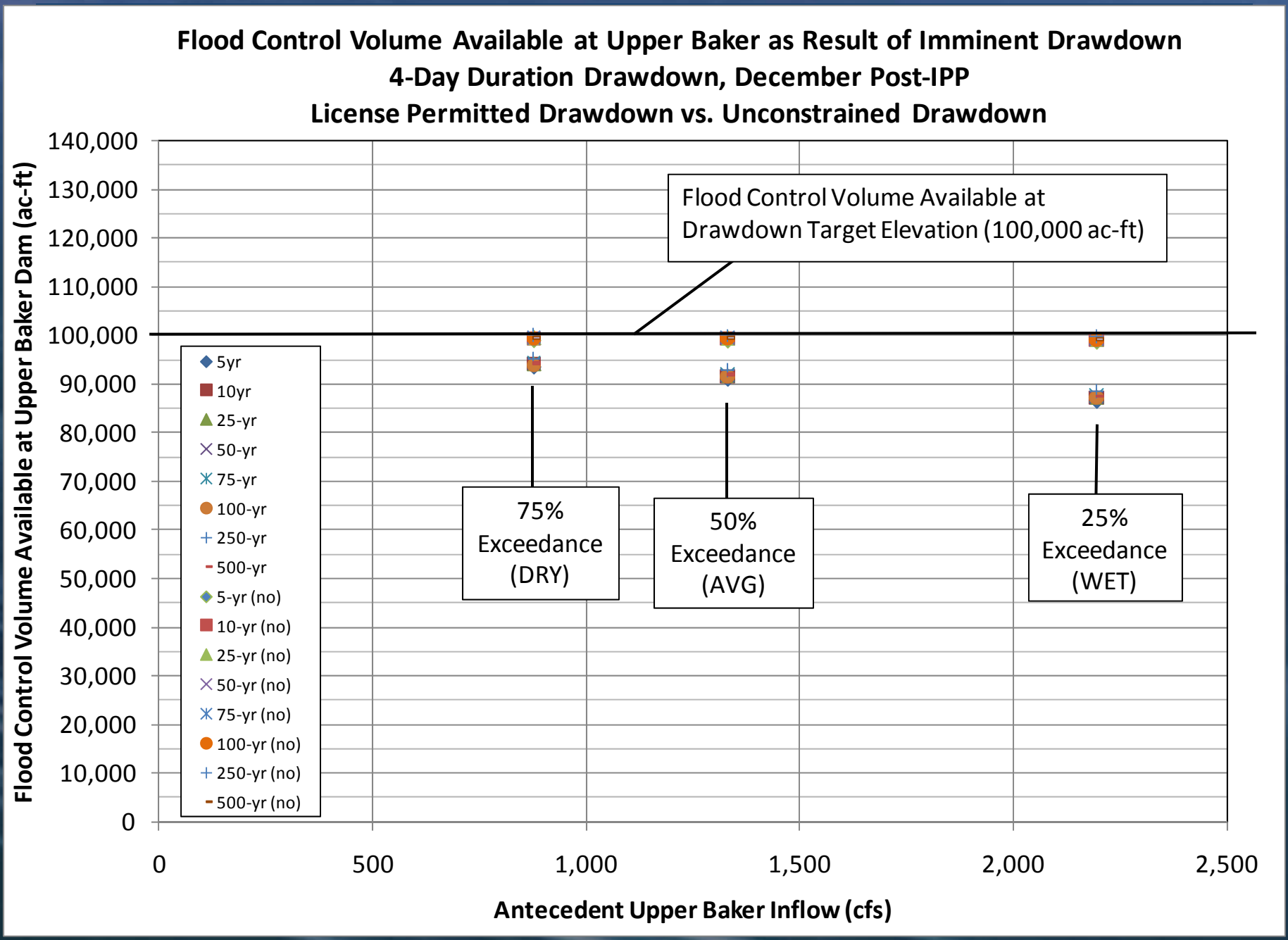

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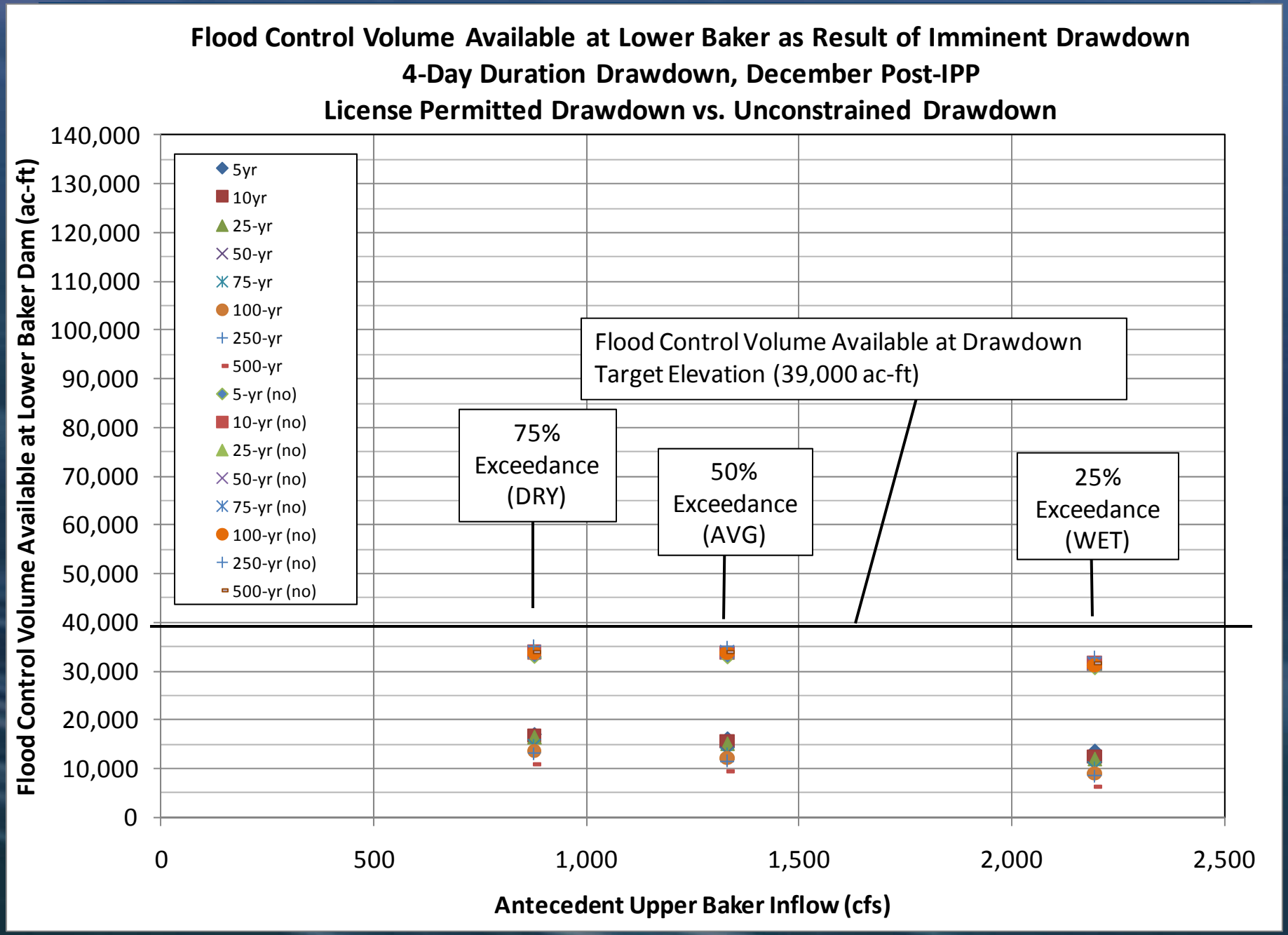

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Procedure - Flood Analysis

- Conducted Flood Analysis for:
  - 5-yr through 500-yr return periods (8)
  - Wet, Average and Dry antecedent conditions (3)
  - Post IPP Constraints and No Constraints (2)
- Total of 48 Runs of Flood Model
- Starting Reservoir Elevations
  - From Drawdown Model Output
- Baker Project operated as per Water Control Manual

Results – Flood Analysis Post-IPP

Comparison of Skagit River near Concrete Regulated Peak Flow Rates
No Drawdown vs. Drawdown
December Dry Antecedent

Flood Event Return Period	No Drawdown	4-Day Duration License Permitted Drawdown		4-Day Duration Alternative Operation Drawdown	
(yrs)	Peak Flow (cfs)	Peak Flow (cfs)	Delta (cfs)	Peak Flow (cfs)	Additional Delta (cfs)
5	103,500	103,500	-	103,100	400
10	128,400	128,400	-	128,300	100
25	167,200	167,200	-	166,900	300
50	186,800	186,800	-	186,800	-
75	210,800	210,600	200	210,600	-
100	223,000	222,700	300	222,700	-
250	279,400	270,900	8,500	270,800	100
500	328,600	311,100	17,500	305,200	5,900

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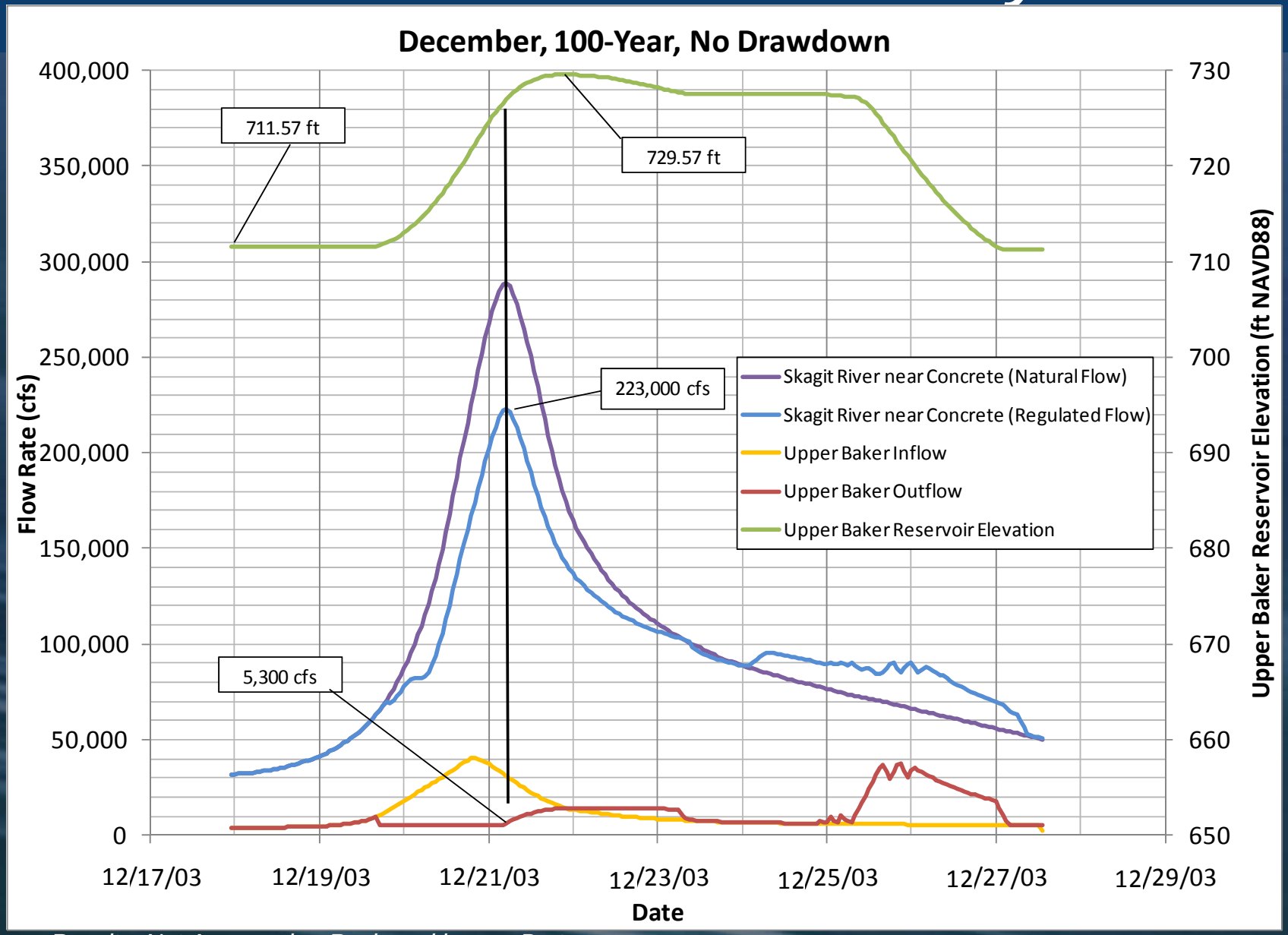
Results – UB Flood Analysis



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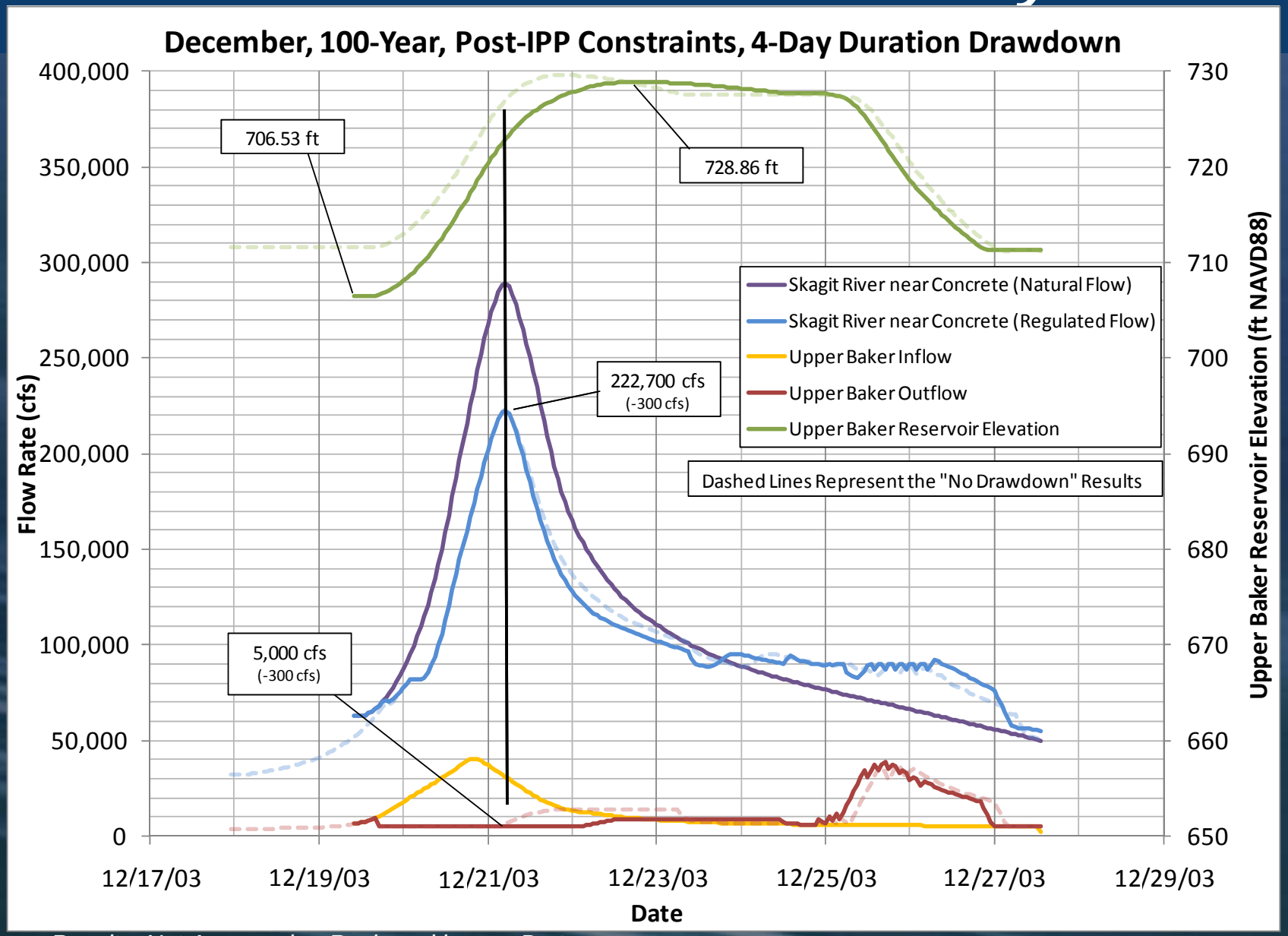

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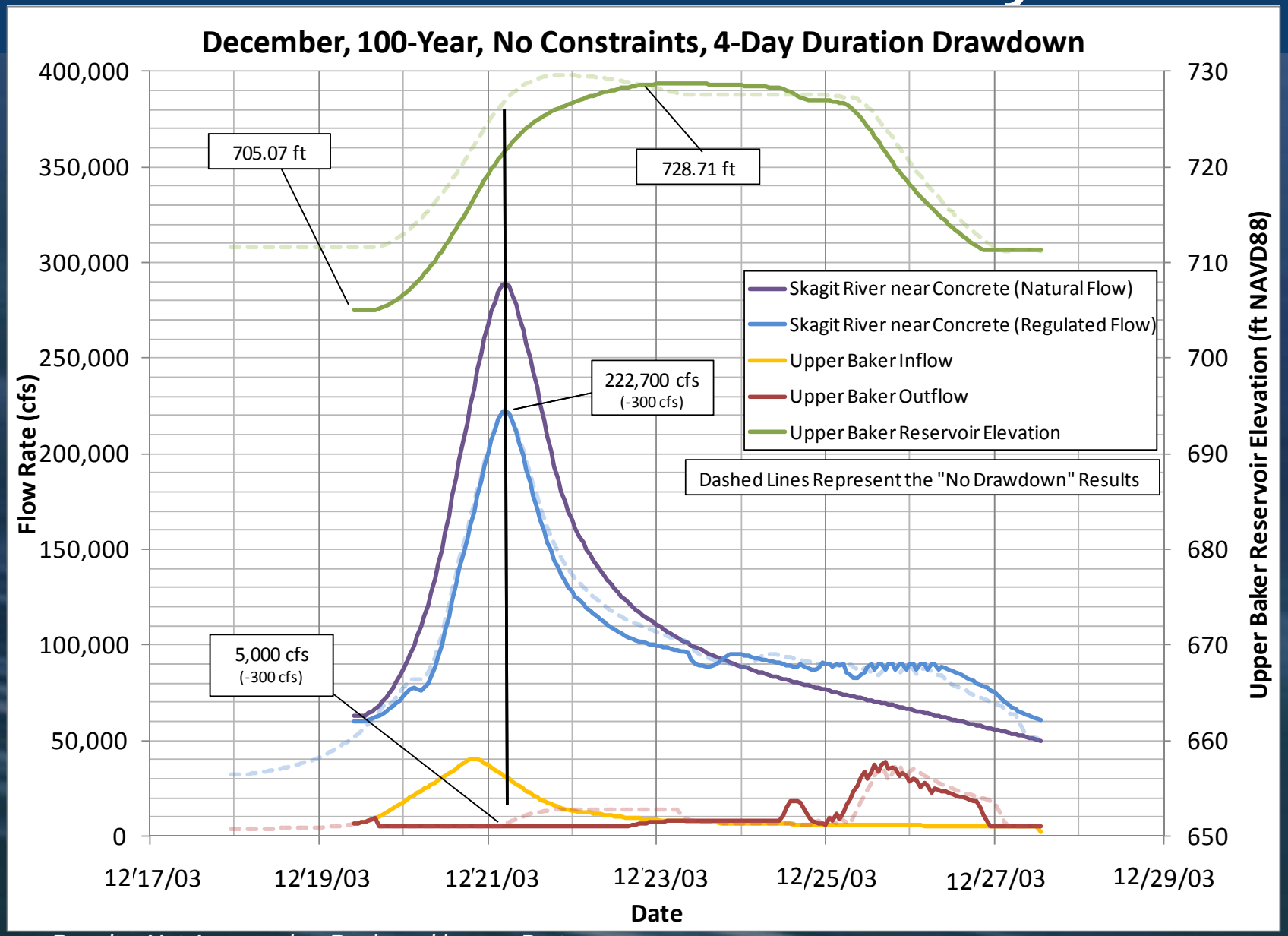
Results – UB Flood Analysis



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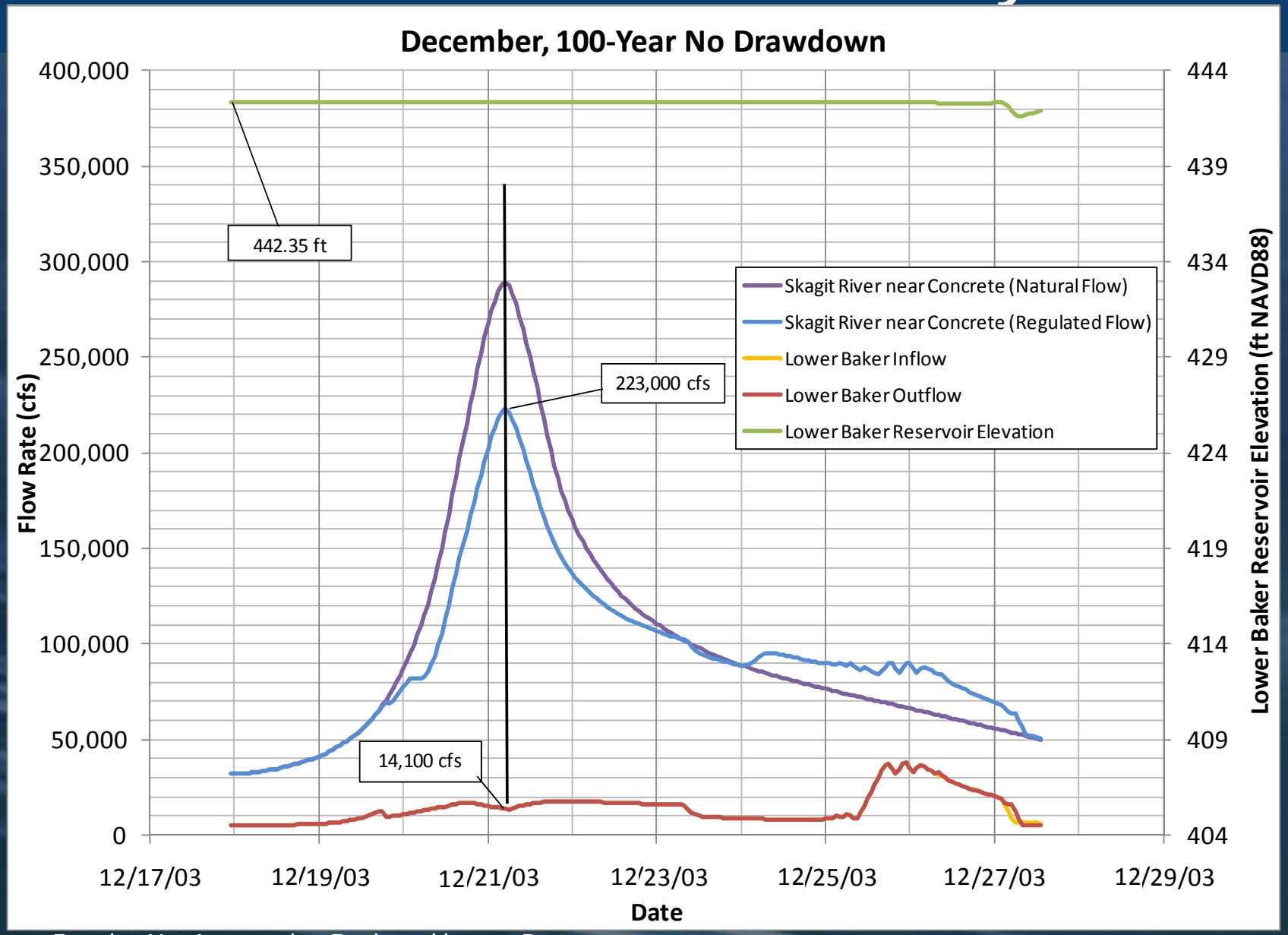
Results – LB Flood Analysis



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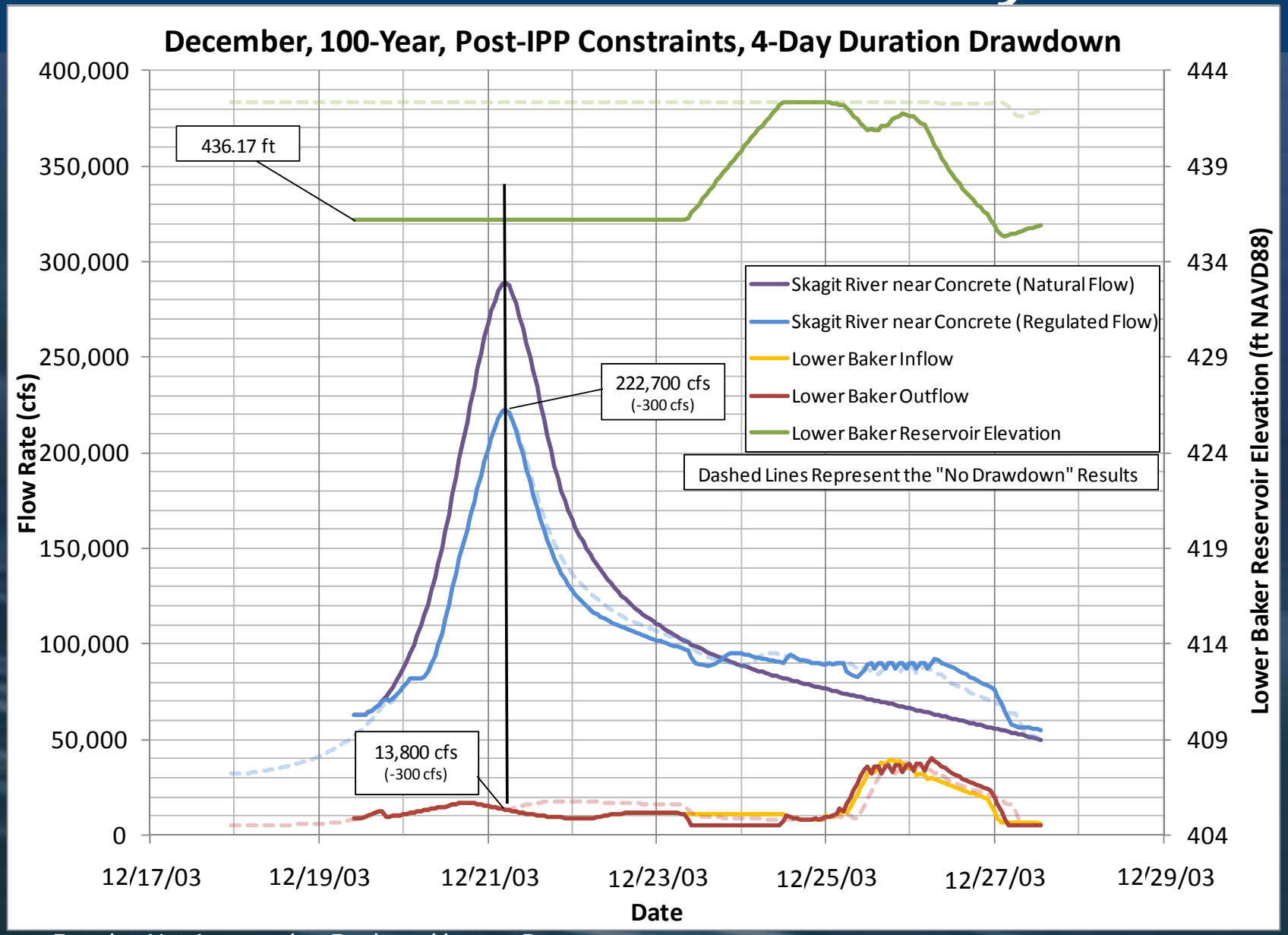
Results – LB Flood Analysis



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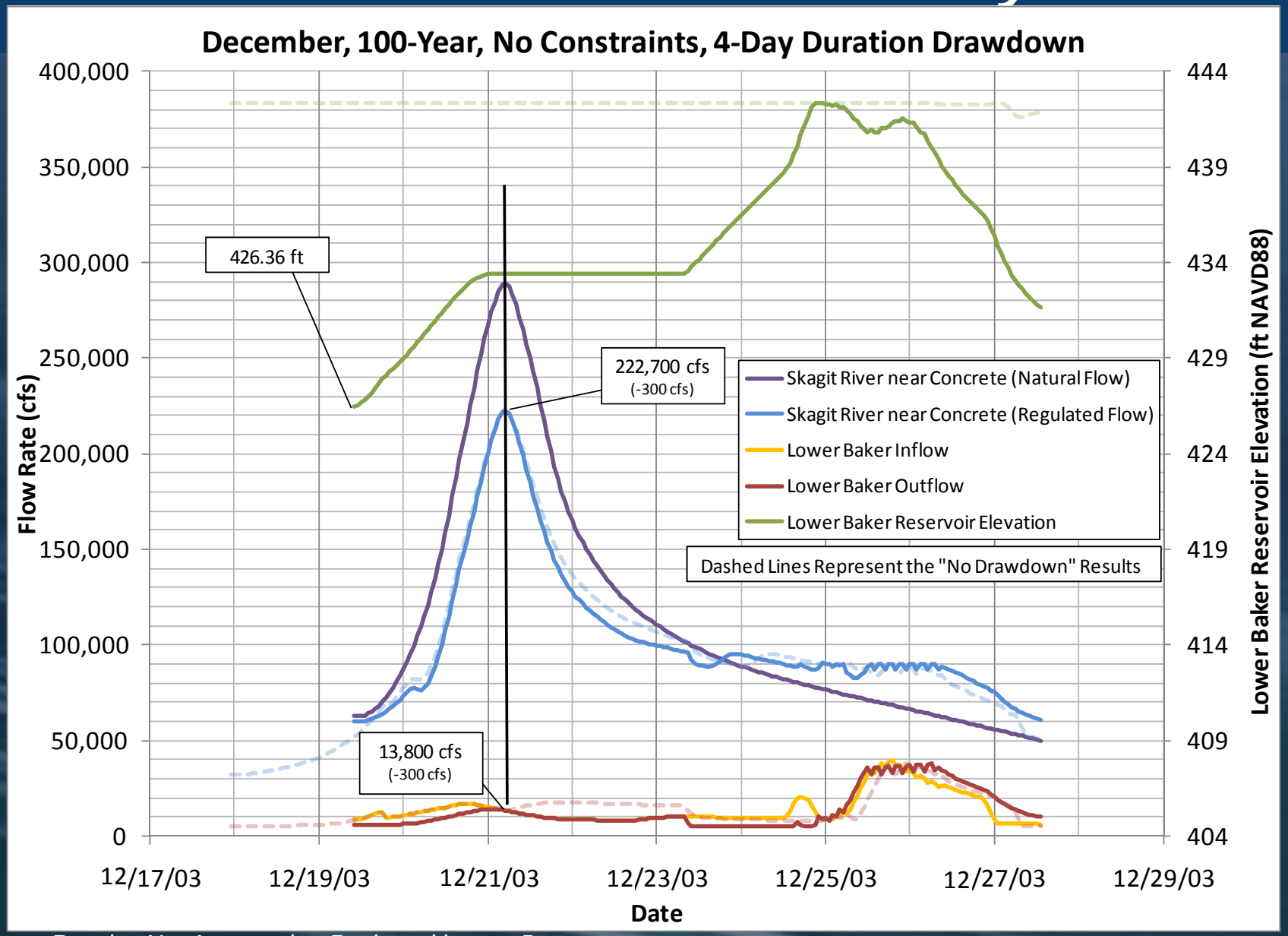
Results – LB Flood Analysis



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Results – Flood Analysis Post-IPP

Comparison of Skagit River near Concrete Regulated Peak Flow Rates
No Drawdown vs. Drawdown
December Dry Antecedent

Flood Event Return Period	No Drawdown	4-Day Duration License Permitted Drawdown		4-Day Duration Alternative Operation Drawdown	
(yrs)	Peak Flow (cfs)	Peak Flow (cfs)	Delta (cfs)	Peak Flow (cfs)	Additional Delta (cfs)
5	103,500	103,500	-	103,100	400
10	128,400	128,400	-	128,300	100
25	167,200	167,200	-	166,900	300
50	186,800	186,800	-	186,800	-
75	210,800	210,600	200	210,600	-
100	223,000	222,700	300	222,700	-
250	279,400	270,900	8,500	270,800	100
500	328,600	311,100	17,500	305,200	5,900

Preliminary Results. Not Approved or Reviewed by any Party

Results – Flood Analysis Post-IPP

Comparison of Skagit River near Concrete Regulated Peak Flow Rates
No Drawdown vs. Drawdown
December Average Antecedent

Flood Event Return Period	No Drawdown	4-Day Duration License Permitted Drawdown		4-Day Duration Alternative Operation Drawdown	
(yrs)	Peak Flow (cfs)	Peak Flow (cfs)	Delta (cfs)	Peak Flow (cfs)	Additional Delta (cfs)
5	103,500	103,500	-	103,200	300
10	128,400	128,400	-	128,300	100
25	167,200	167,200	-	166,900	300
50	186,800	186,800	-	186,800	-
75	210,800	210,600	200	210,600	-
100	223,000	222,700	300	222,700	-
250	279,400	271,000	8,400	270,800	200
500	328,600	312,800	15,800	305,200	7,600

Preliminary Results. Not Approved or Reviewed by any Party

Results – Flood Analysis Post-IPP

Comparison of Skagit River near Concrete Regulated Peak Flow Rates
No Drawdown vs. Drawdown
December Wet Antecedent

Flood Event Return Period	No Drawdown	4-Day Duration License Permitted Drawdown		4-Day Duration Alternative Operation Drawdown	
(yrs)	Peak Flow (cfs)	Peak Flow (cfs)	Delta (cfs)	Peak Flow (cfs)	Additional Delta (cfs)
5	103,500	103,500	-	103,500	-
10	128,400	128,400	-	128,400	-
25	167,200	167,200	-	167,200	-
50	186,800	186,800	-	186,800	-
75	210,800	210,600	200	210,600	-
100	223,000	222,700	300	222,700	-
250	279,400	271,600	7,800	270,800	800
500	328,600	316,900	11,700	305,300	11,600

Preliminary Results. Not Approved or Reviewed by any Party

Final Considerations

- Analysis Assumptions:
  - Drawdown Analysis
    - Reservoir elevations at start of drawdown = rule curve elevations
    - 4-day duration drawdown
    - 18-hour period on rising limb where hydrologic conditions would allow lifting of constraints
    - Assume DRY (75% exceedance), AVG (50% exceedance) and WET (25% exceedance) antecedent conditions
  - Flood Analysis
    - Operation of Baker Project as per Water Control Manual

Next Steps

- Conduct analysis for remaining periods for Post-IPP
- Presentation of results to ARG
- Conduct analysis for all periods for IPP
- Presentation of results to ARG


Thank you for your time.
Comments and Questions……