OPTIMIZATION OF BRADLEY LAKE HYDROPOWER USING LAKE ELEVATION RULE CURVE MODELING

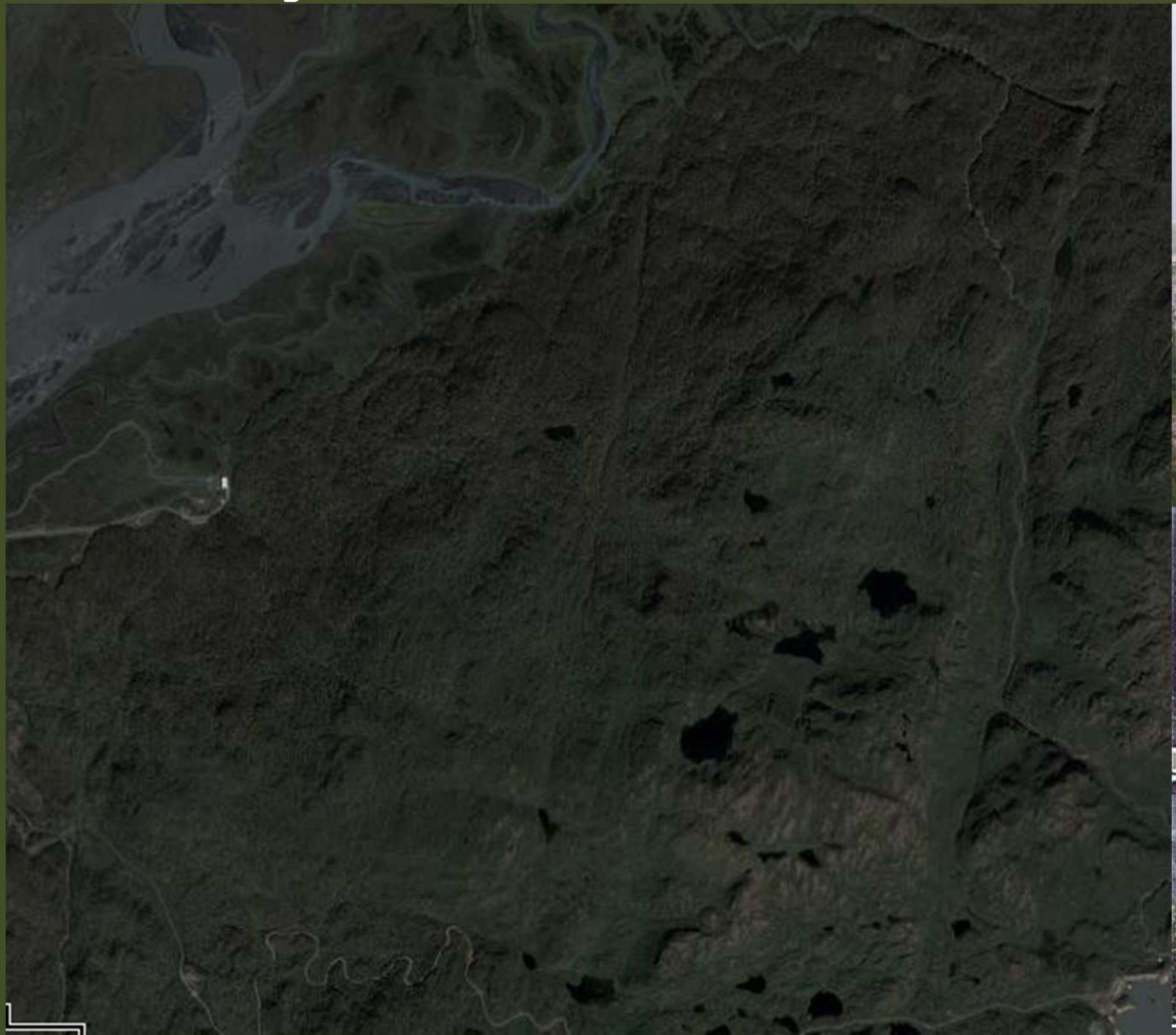
EDMUND PARVIN
SCHOOL OF ENGINEERING, UNIVERSITY OF ALASKA, ANCHORAGE
APRIL 06. 2011

UAA UNIVERSITY of ALASKA ANCHORAGE

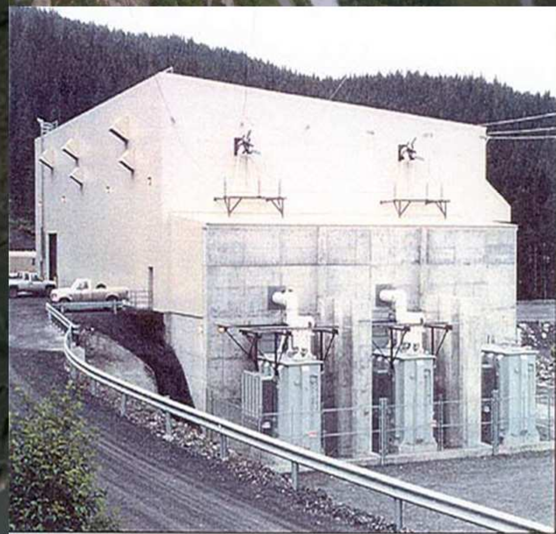
Outline

- Background
  - Bradley Lake
  - Rule Curves
- Research Goals
- Model Development
  - Components
  - Limitations
  - Testing
- Results

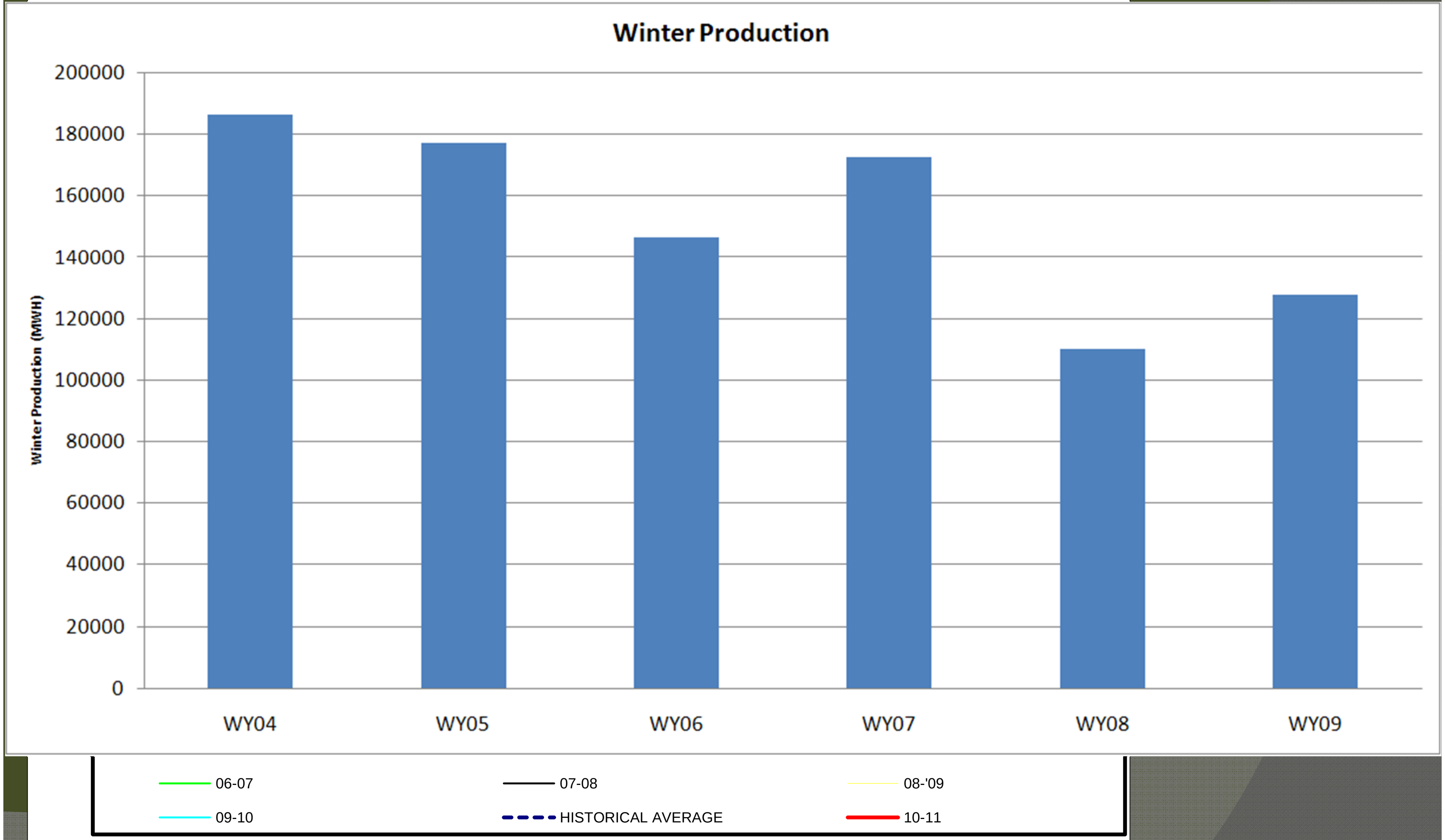
Bradley Lake Hydro Electric Facility



Earth Images (Google earth, 2010)



BRADLEY LAKE LEVEL
June 2003 - October 2010

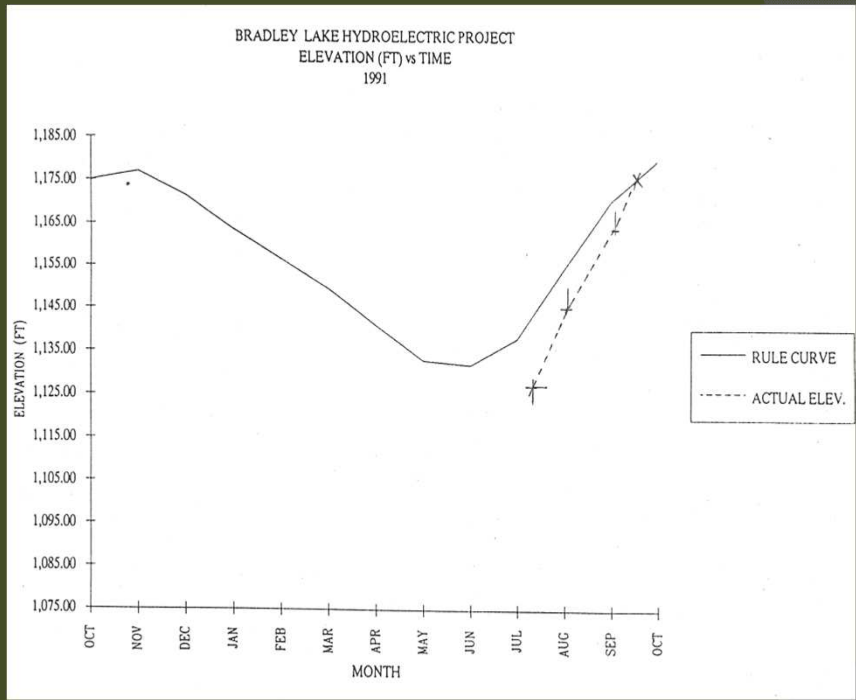


Research Goals

- Maximize Energy Production
- Maximize Winter Production
- Effects of seasonal operational shutdowns
- Use of lake elevation rule curves, as operational constraints to Bradley Lake Hydro Electric Facility

Rule Curves

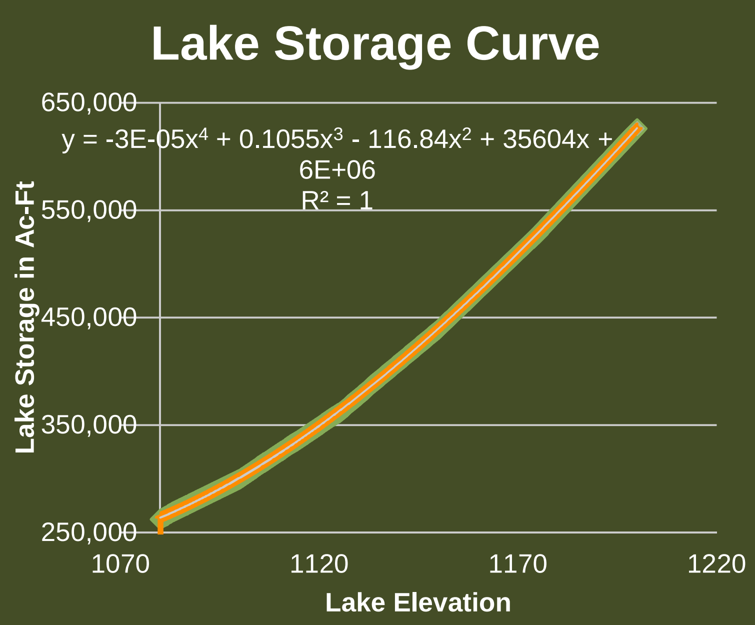
- A Rule Curve is a guide established to regulate and manage optimum pool elevations for yearly operations at impoundments. (US ACE, 2010).

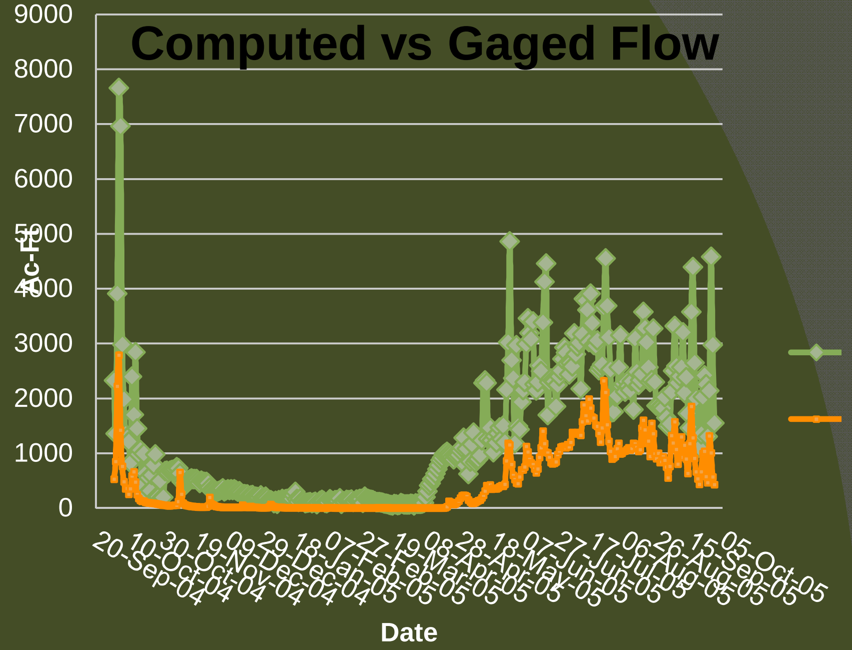


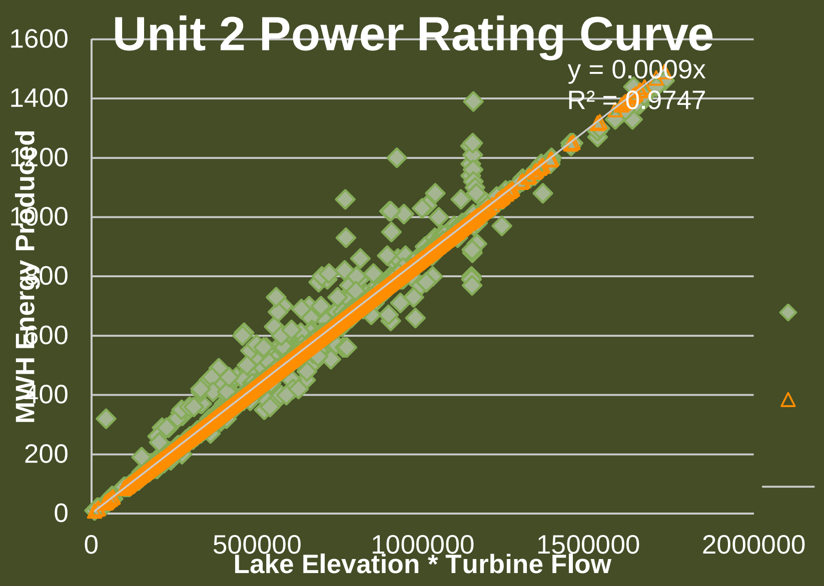
Available Data

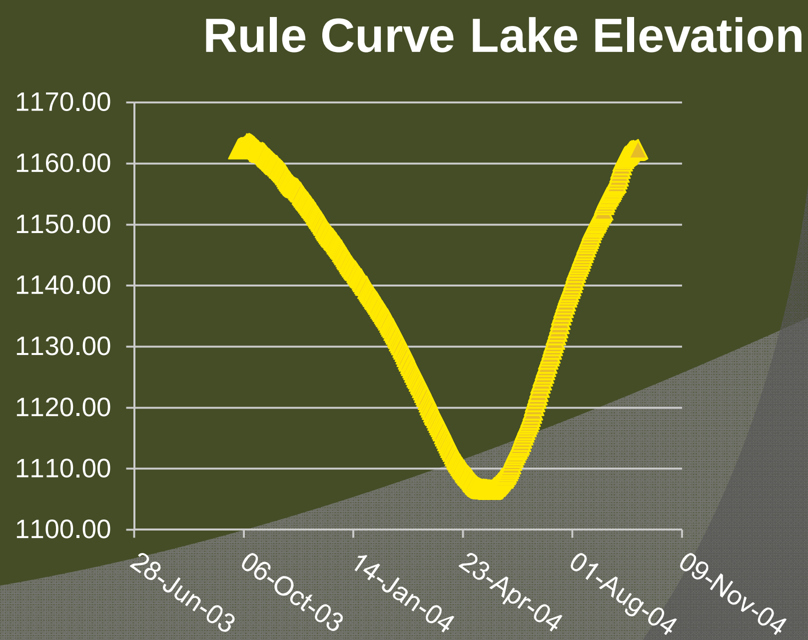
Homer Electric Association Provided the following

- Daily Turbine flow data with corresponding energy production (July 23,2003 to Nov. 26, 2009)
- Daily Lake Elevations (June 1,2003 to present)
- Reservoir Storage Table
- Fish bypass release


Lake Storage Curve
y = -3E-05x4 + 0.1055x3 - 116.84x2 + 35604x + 6E+06
R² = 1
Lake Storage in Ac-Ft
650,000
550,000
450,000
350,000
250,000
1070
1120
1170
1220
Lake Elevation

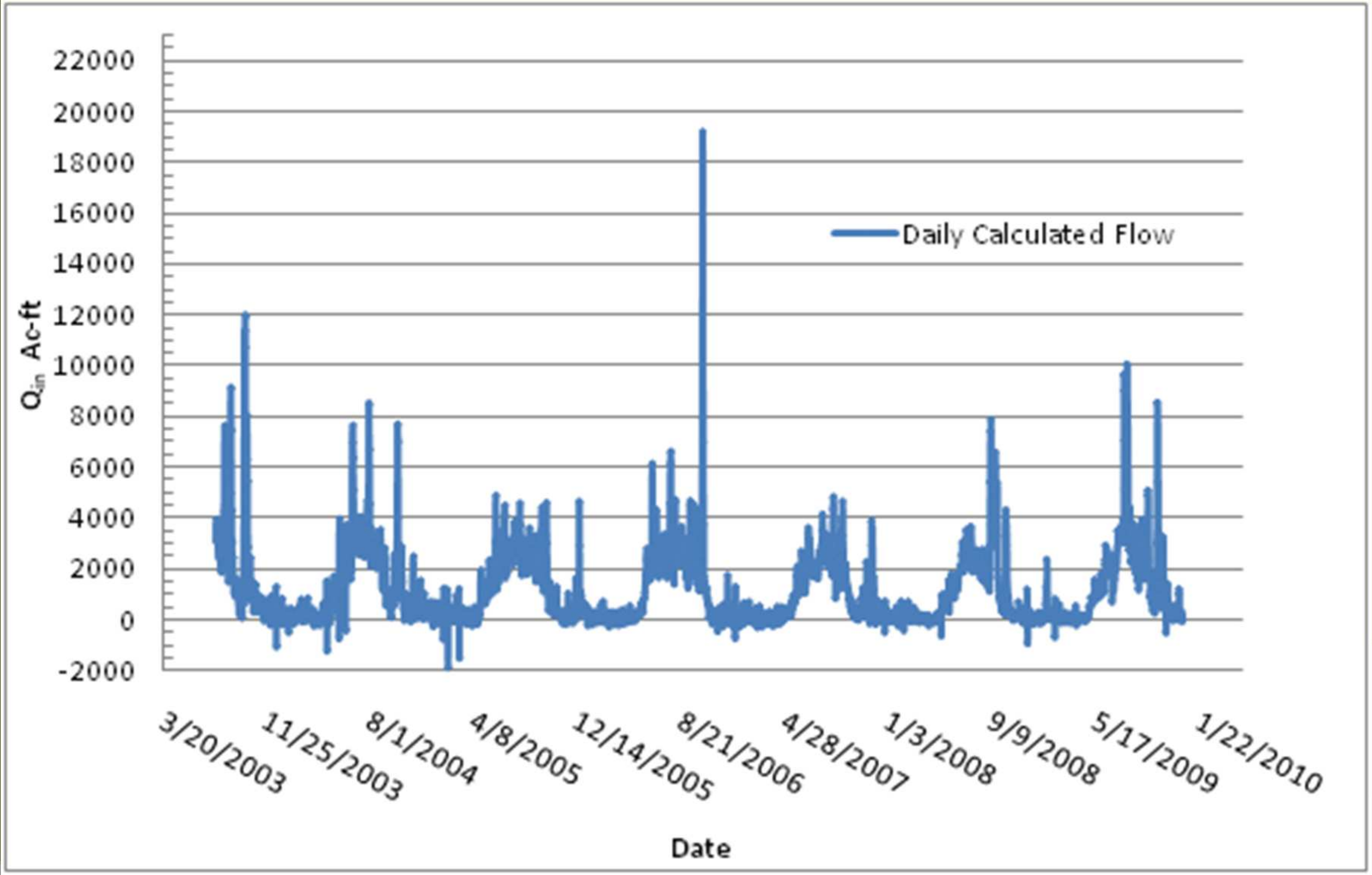

Computed vs Gaged Flow
Ac-Ft
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Date


Unit 2 Power Rating Curve
y = 0.0009x
R² = 0.9747
MWH Energy Produced
1600
1400
1200
1000
800
600
400
200
0
0
500000
1000000
1500000
2000000
Lake Elevation * Turbine Flow


Rule Curve Lake Elevation
1170.00
1160.00
1150.00
1140.00
1130.00
1120.00
1110.00
1100.00
28-Jun-03
06-Oct-03
14-Jan-04
23-Apr-04
01-Aug-04
09-Nov-04

Water Balance

ΔLake Storage (ac-ft) + turbine flow (ac-ft) + fish bypass release (ac-ft)= Total Daily Flow (ac-ft).



Water Balance

Second Approach:

$(\sum Q1_{n:n+15}) + (\sum Q2_{n:n+15}) + (\sum Q3_{n:n+15}) - ((V_{n-}V_{n+15})/15 =$ Q/d in Ac-ft

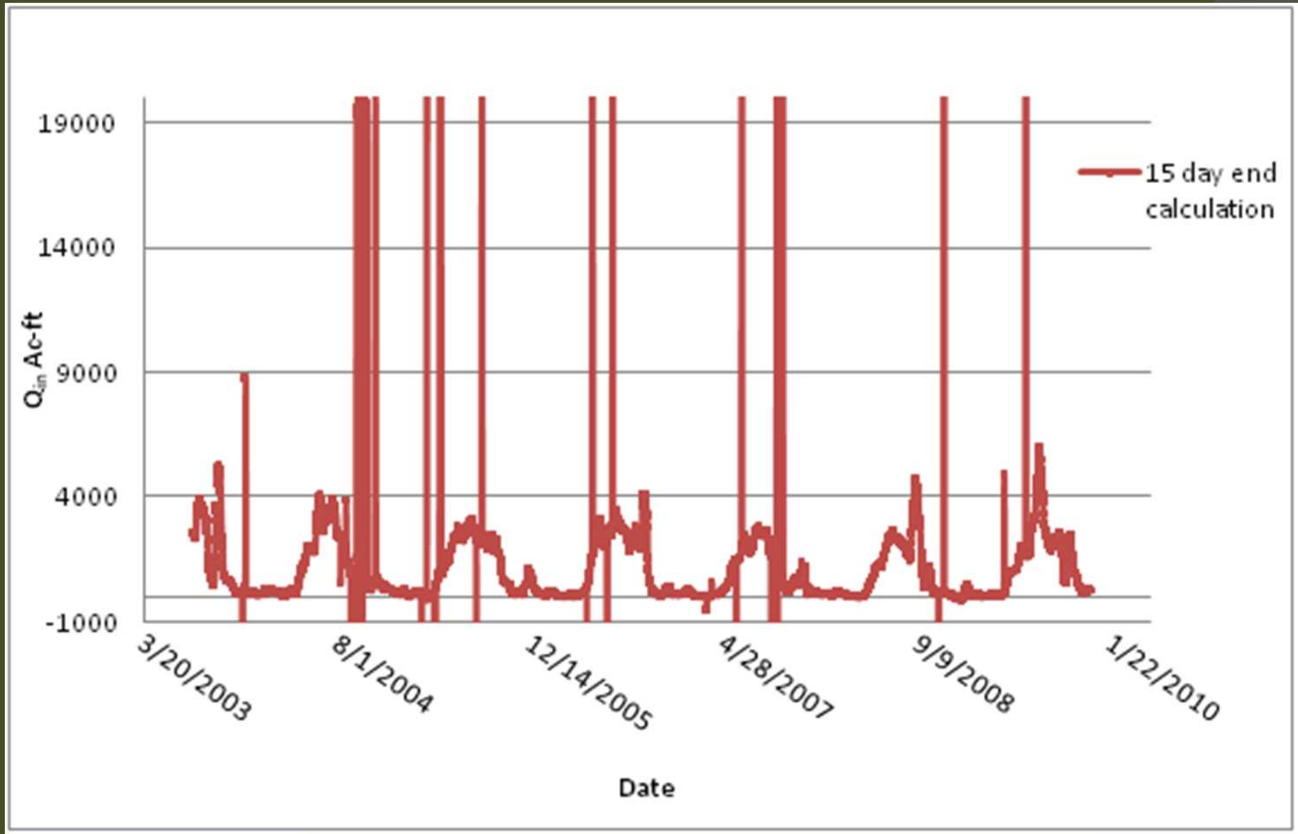
Q = Flow into the lake

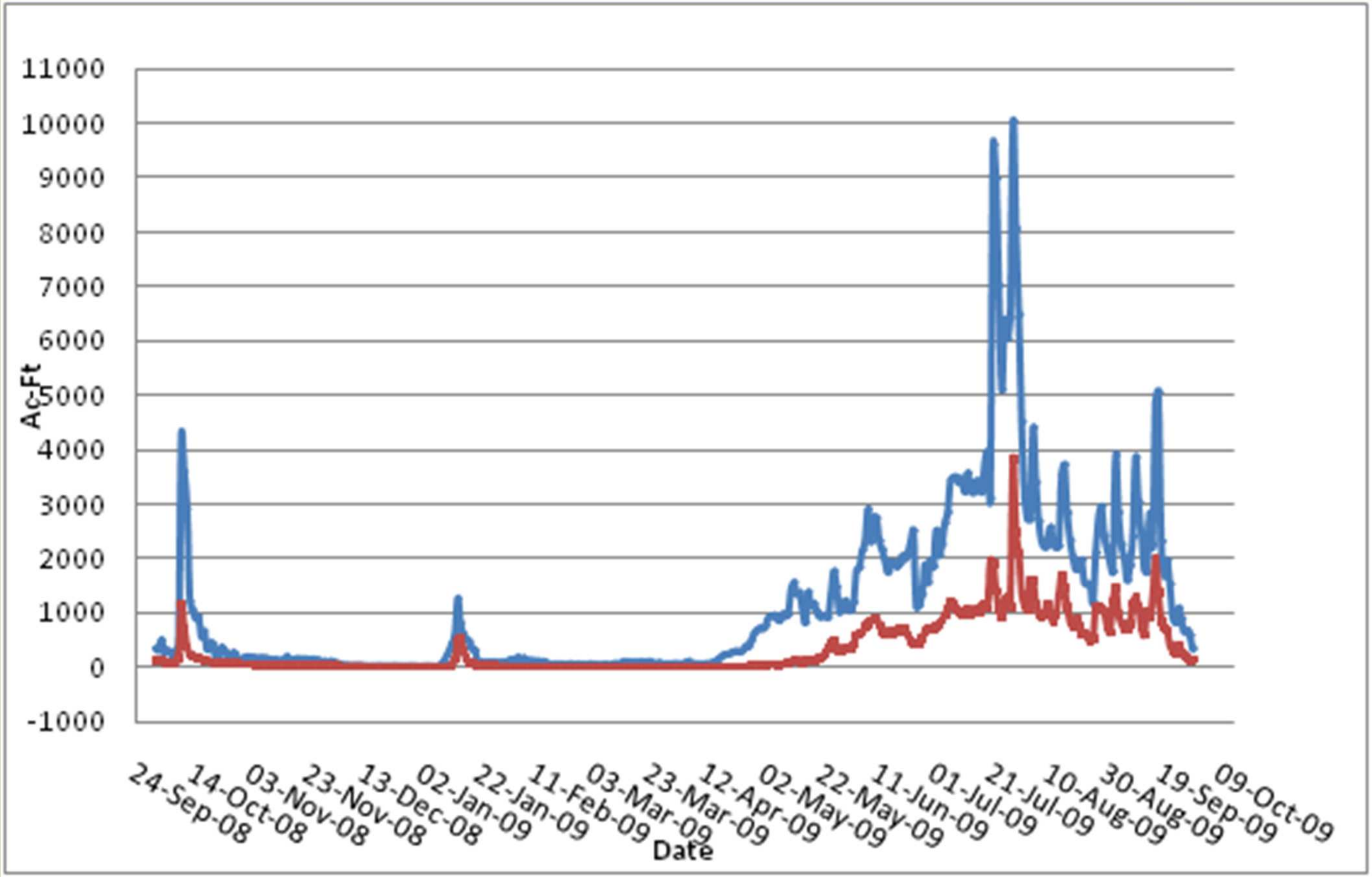
Q1 = Turbine 1 flow ac-ft/d

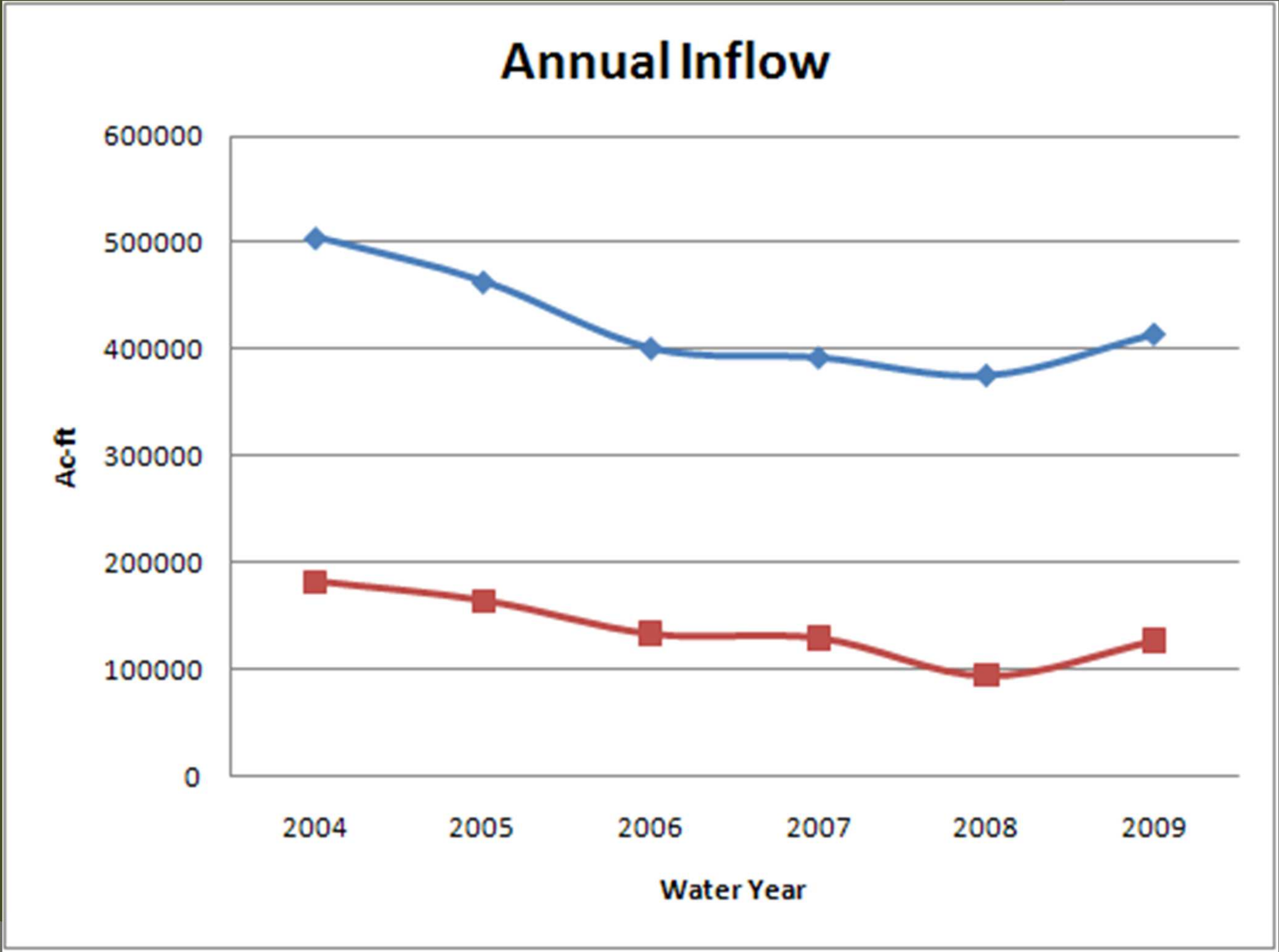
Q2 = Turbine2 flow ac-ft/d

Q3= Fish Bypass release ac-ft/d

V= lake Storage




11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
Ac-Ft
24-Sep-08
14-Oct-08
03-Nov-08
23-Nov-08
13-Dec-08
02-Jan-09
22-Jan-09
11-Feb-09
03-Mar-09
23-Mar-09
12-Apr-09
02-May-09
22-May-09
11-Jun-09
01-Jul-09
21-Jul-09
10-Aug-09
30-Aug-09
19-Sep-09
09-Oct-09
Date


Annual Inflow
600000
500000
400000
300000
200000
100000
0
Ac-ft
2004
2005
2006
2007
2008
2009
Water Year

Model

- Constraints
  - Maximum turbine flow

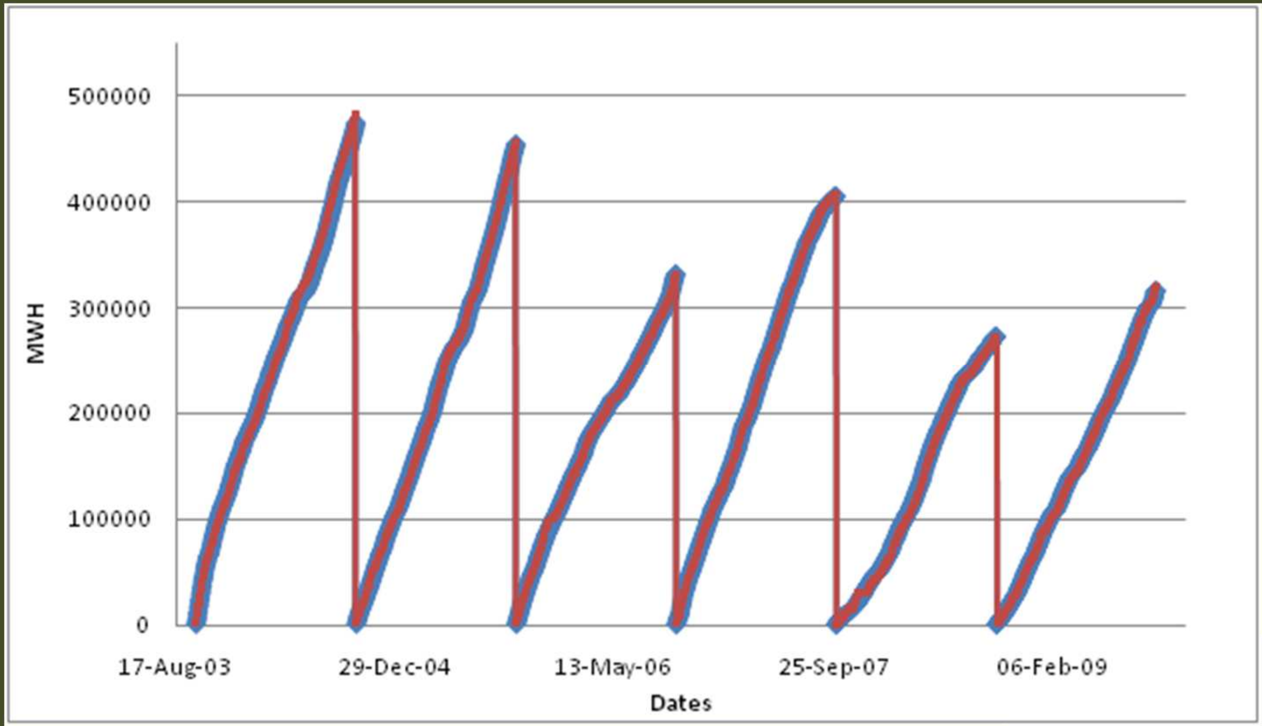
    3000 ac-ft/d
  - Maximum lake elevation 1180 ft.
  - Intake elevation

    1080 ft.
- Limitations
  - Model does not draw lake down in anticipation of a rain event
  - Model always returns model lake elevation to rule curve elevation

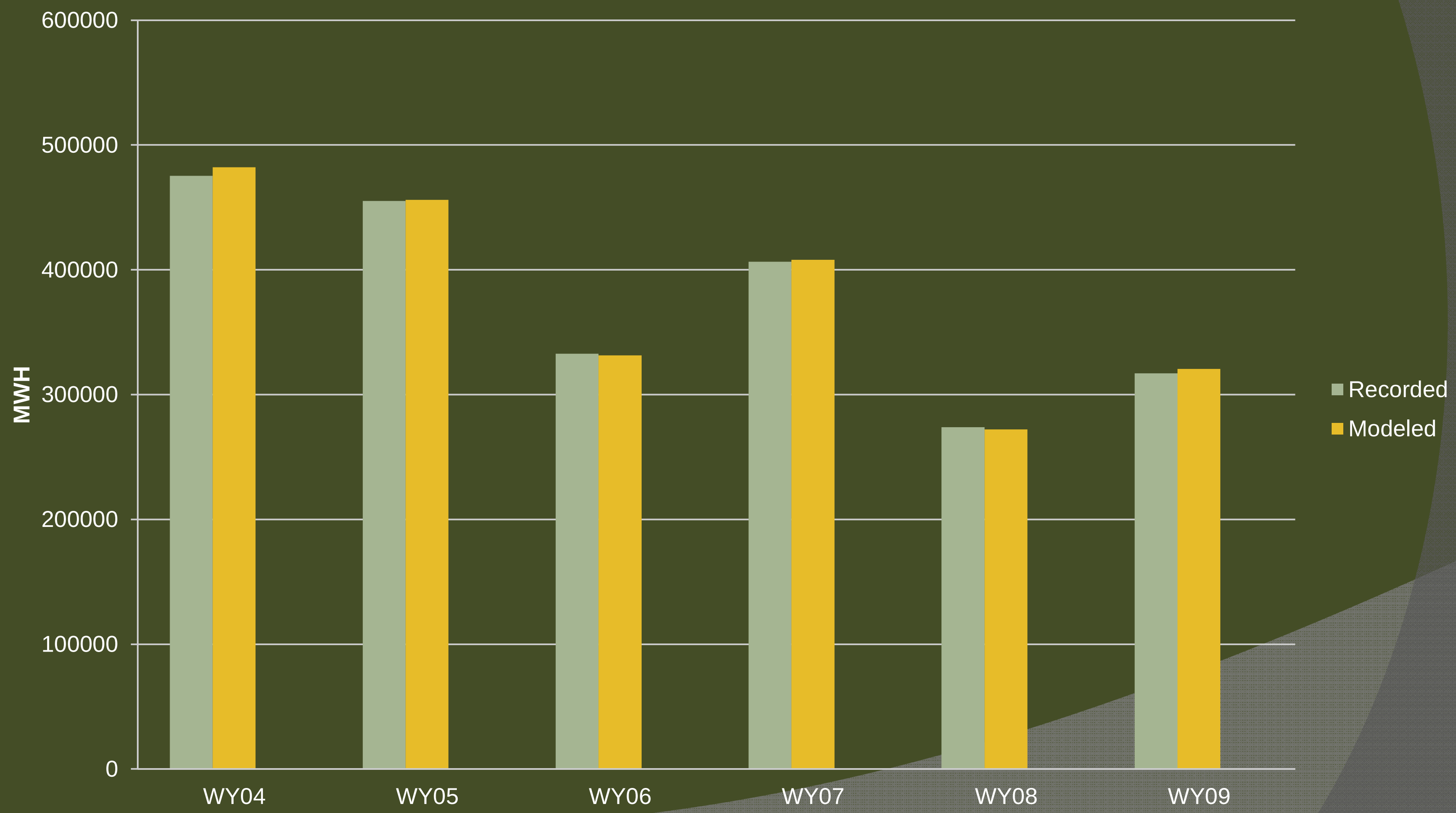
Model Test

- The recorded lake elevations from July 23rd, 2003 to Nov. 26th,2009 were entered into the model as a rule curve.
- Modeled data was 0.43% higher then actual power generation
- Actual Power Generation= 2,260,689 MWH
- Modeled Power Generation= 2,270,502 MWH
- Difference= 9813 MWH

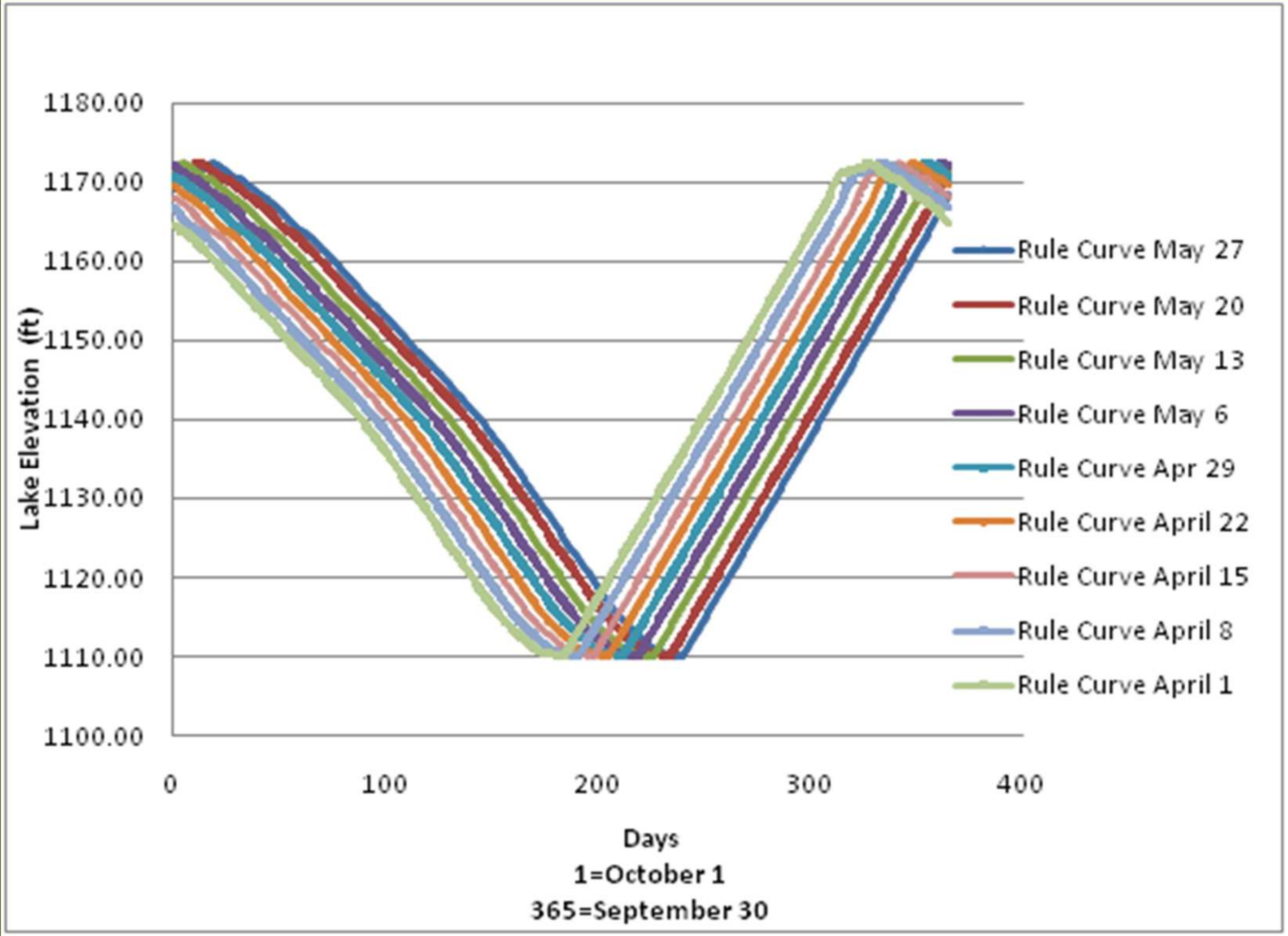
Model Testing



Model Testing

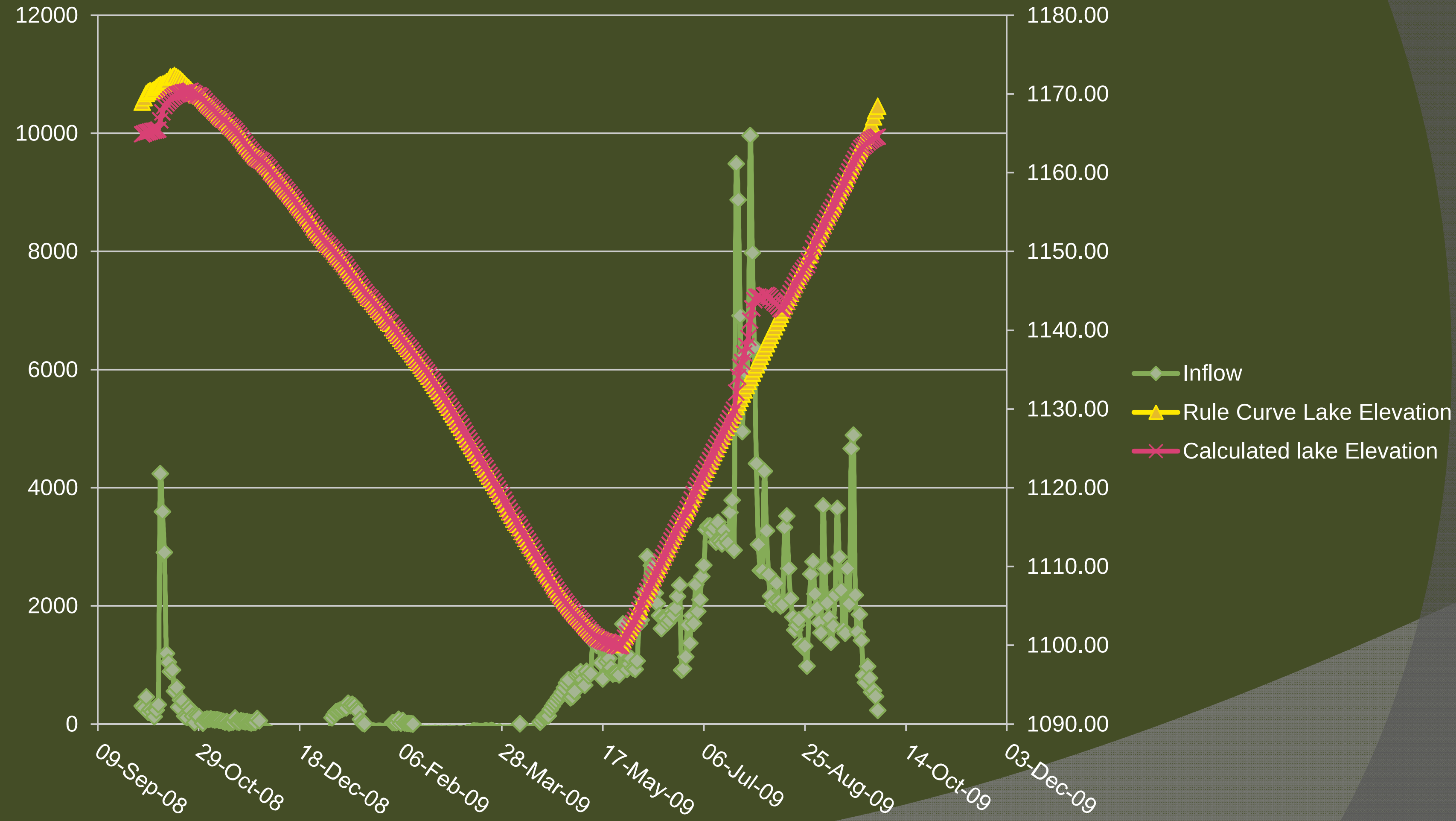


Time Shift



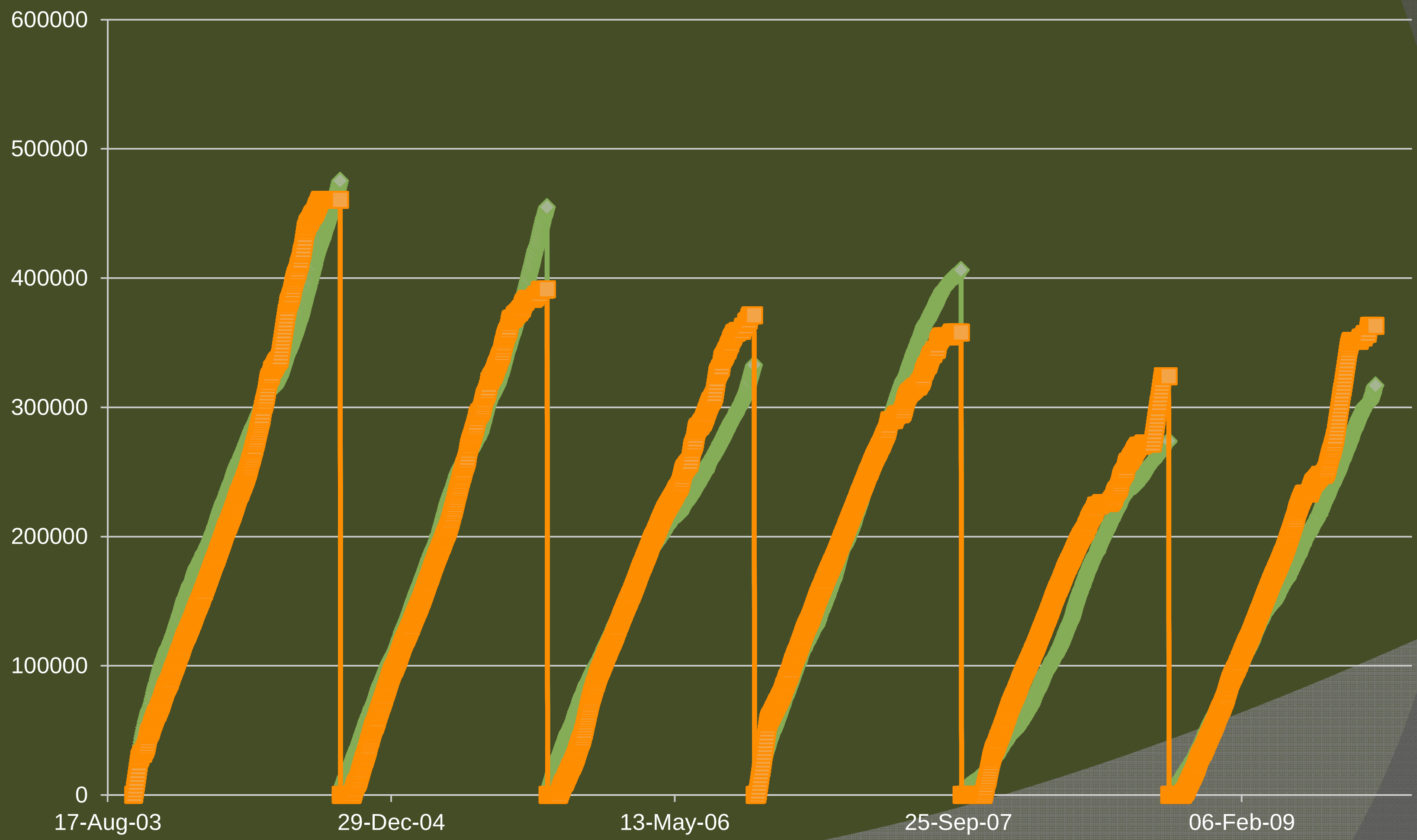
1180.00
1170.00
1160.00
1150.00
1140.00
1130.00
1120.00
1110.00
1100.00
Lake Elevation (ft)
0
100
200
300
400
Days
1=October 1
365=September 30
Rule Curve May 27
Rule Curve May 20
Rule Curve May 13
Rule Curve May 6
Rule Curve Apr 29
Rule Curve April 22
Rule Curve April 15
Rule Curve April 8
Rule Curve April 1

Time Shift



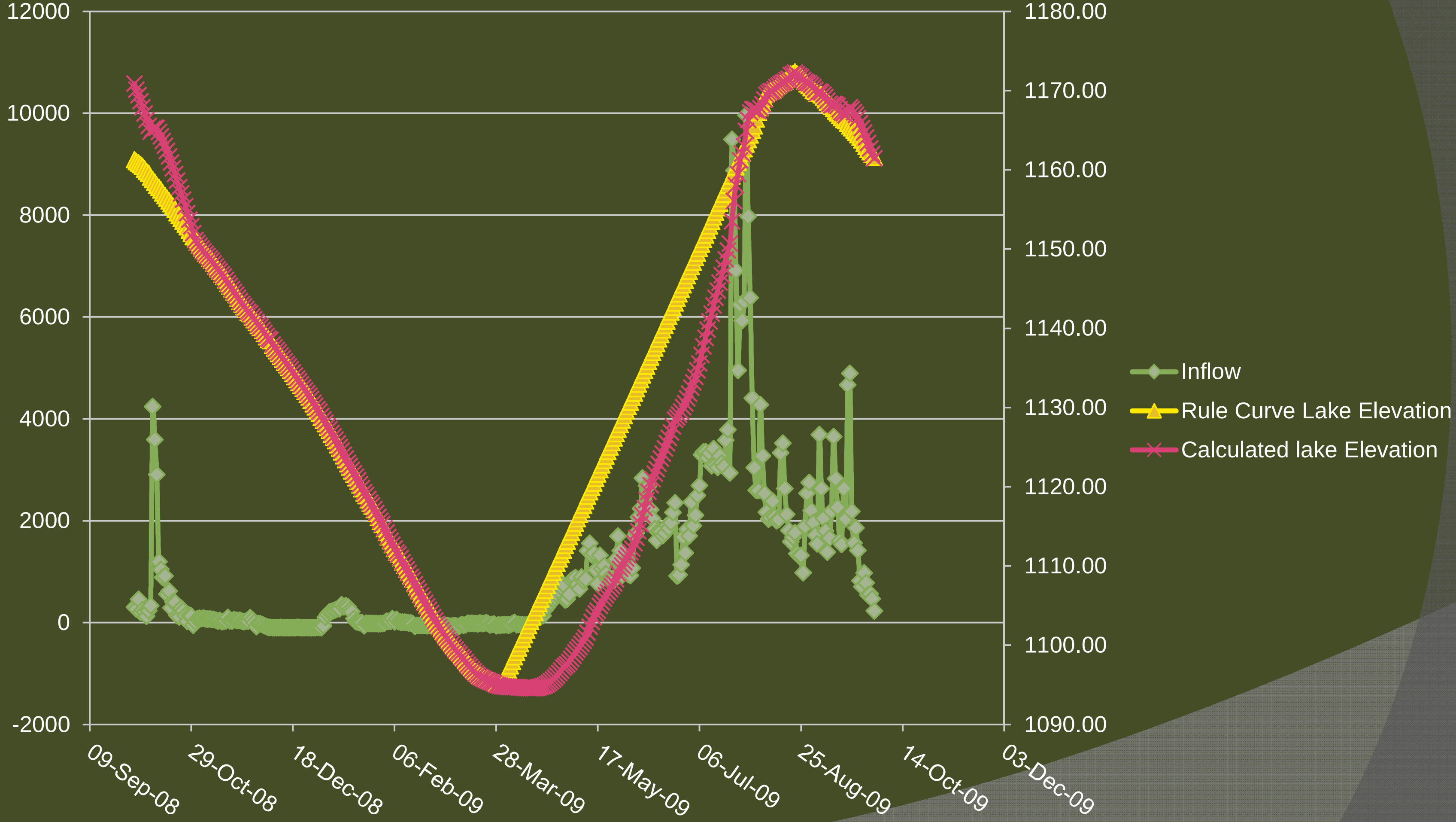
12000
10000
8000
6000
4000
2000
0
1180.00
1170.00
1160.00
1150.00
1140.00
1130.00
1120.00
1110.00
1100.00
1090.00
09-Sep-08
29-Oct-08
18-Dec-08
06-Feb-09
28-Mar-09
17-May-09
06-Jul-09
25-Aug-09
14-Oct-09
03-Dec-09
Inflow
Rule Curve Lake Elevation
Calculated lake Elevation

Time Shift



UAA UNIVERSITY of ALASKA ANCHORAGE

Time Shift

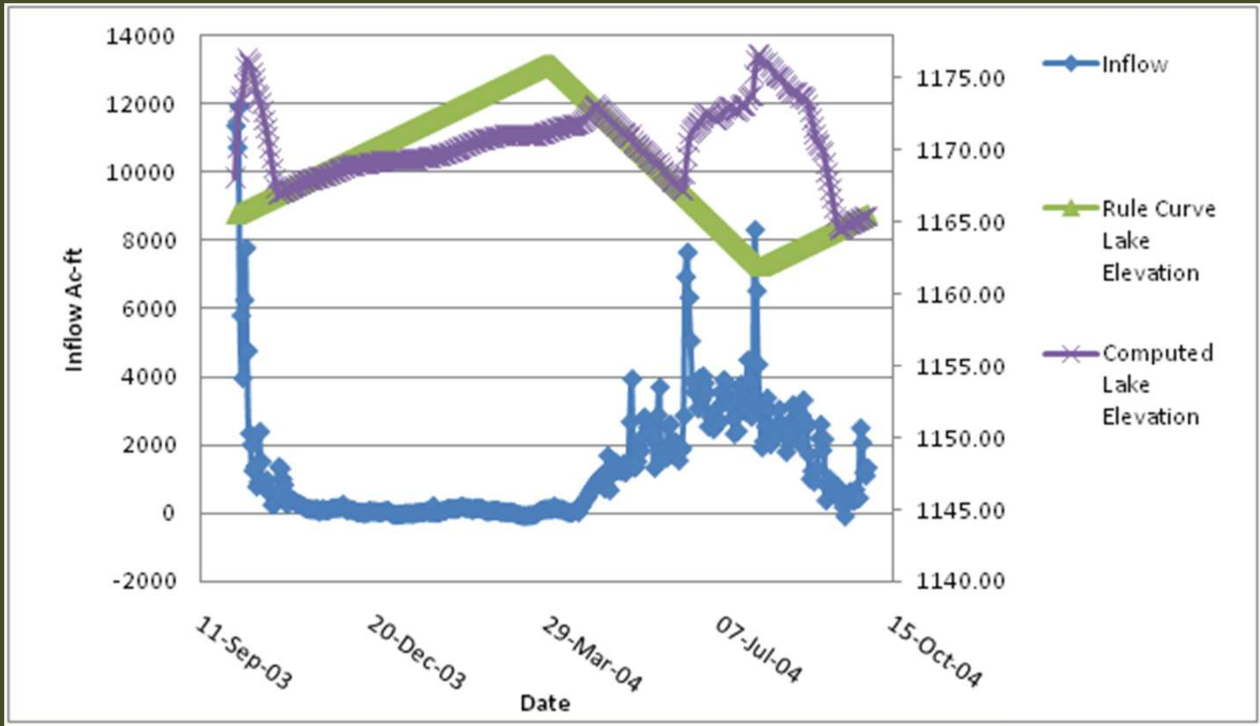


UNIVERSITY of ALASKA ANCHORAGE

Time Shift

600000
500000
400000
300000
200000
100000
0
17-Aug-03
29-Dec-04
13-May-06
25-Sep-07
06-Feb-09

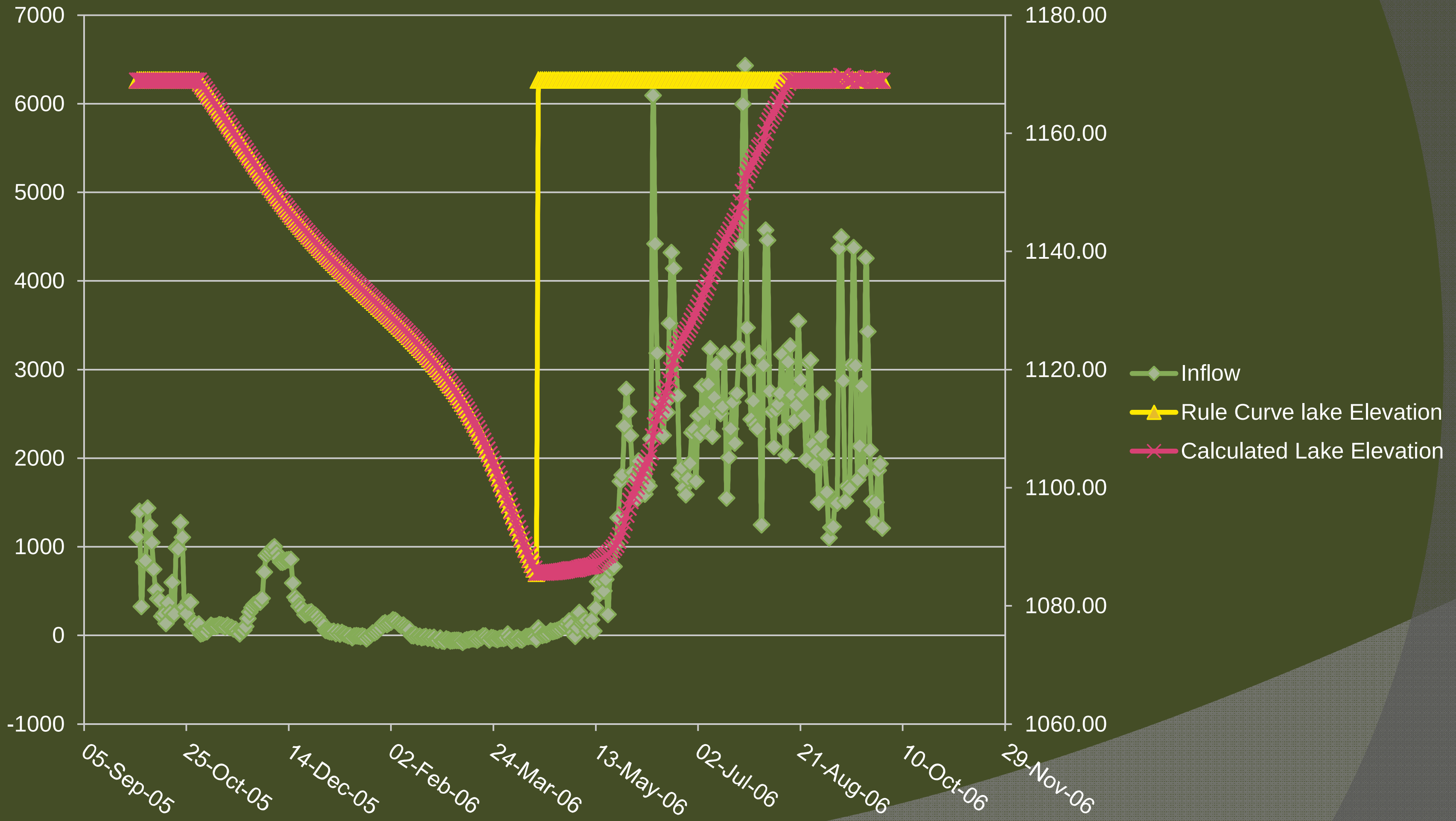
Maximized Production



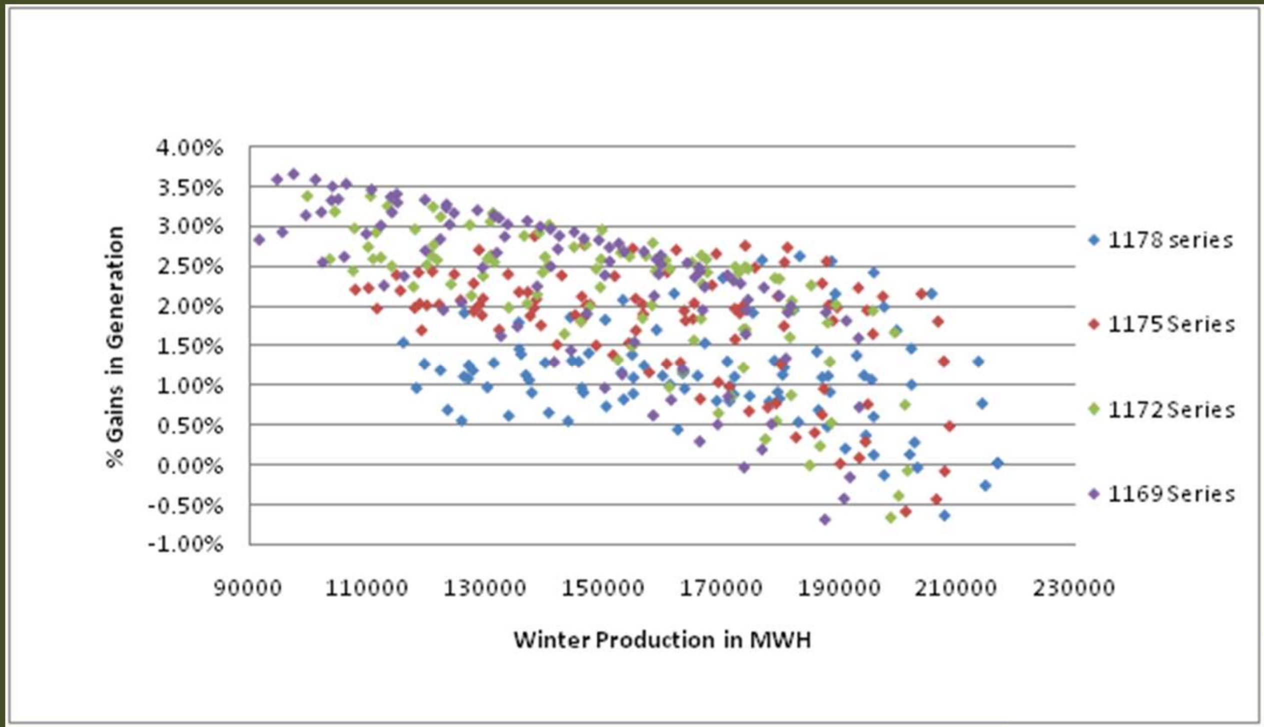
Maximized Production

- 3.99% gains in overall production
- 93,446-93,868 MWH increase in production
- Estimated 9.3 million in increased revenue during study period. Assuming 10 cent per kilowatt cost to consumer
- Produces 97 % of annual production from May to September
- Drastically reduces winter production

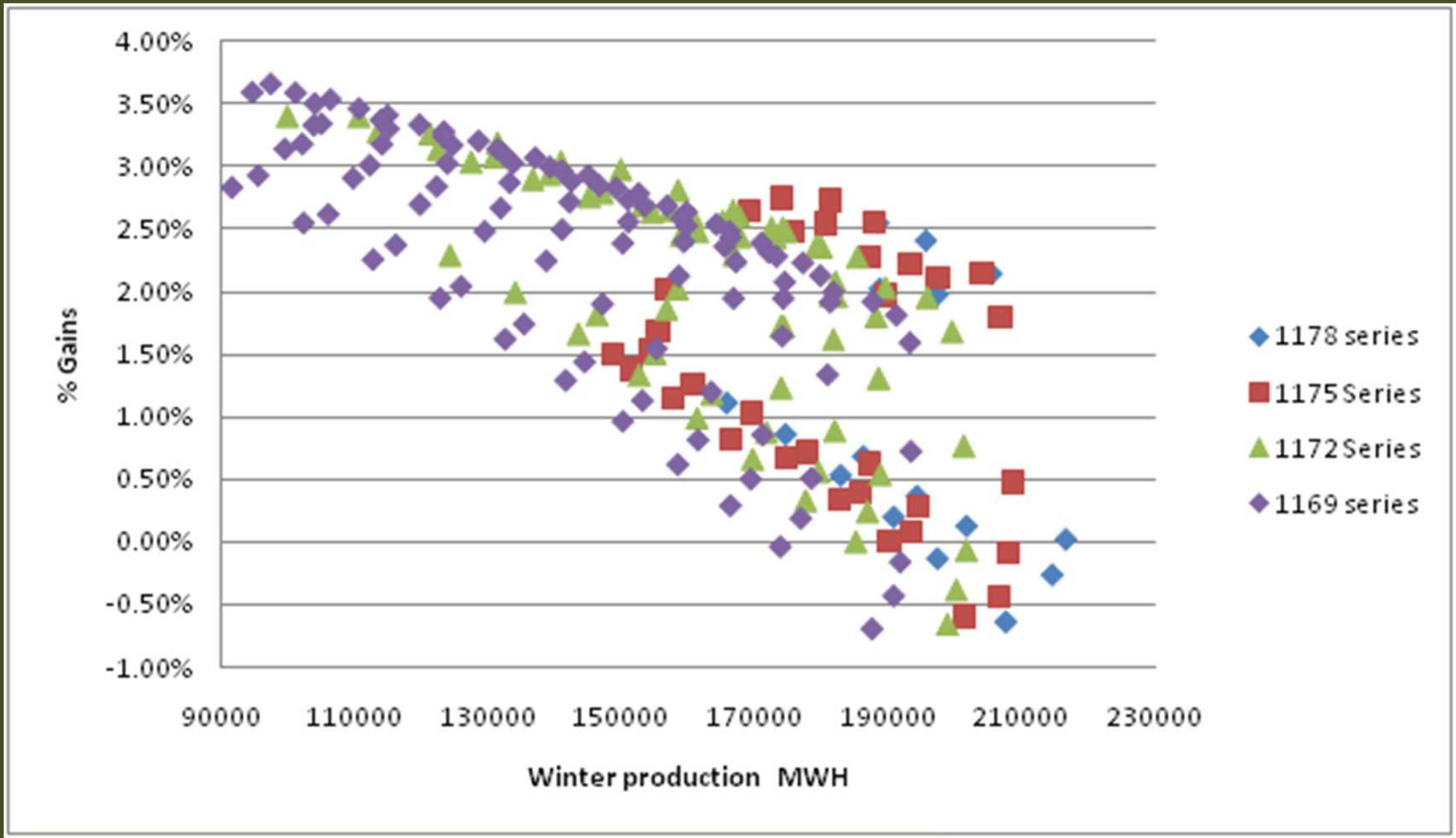
Maximizing Winter Production



Results


% Gains in Generation
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
90000
110000
130000
150000
170000
190000
210000
230000
Winter Production in MWH
1178 series
1175 Series
1172 Series
1169 Series

Results



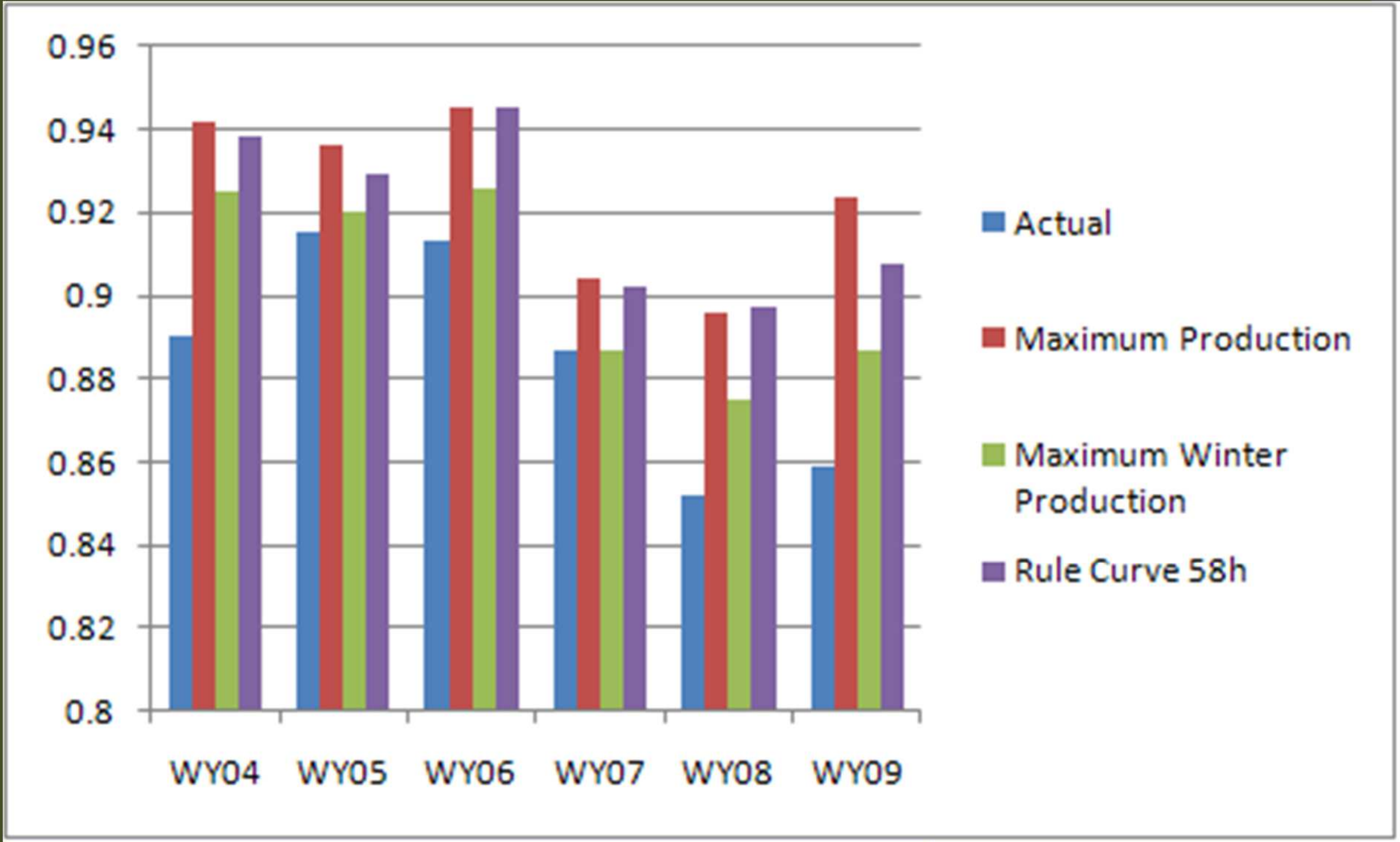
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
% Gains
90000
110000
130000
150000
170000
190000
210000
230000
Winter production MWH
1178 series
1175 Series
1172 Series
1169 series

Results

	Actual	Maximum Production	Maximum Winter Production	Rule Curve 58H
		3.99%	2.13%	3.66%
WY04	0.890	0.942	0.925	0.938
WY05	0.915	0.936	0.920	0.929
WY06	0.913	0.945	0.926	0.945
WY07	0.887	0.904	0.887	0.902
WY08	0.852	0.896	0.875	0.897
WY09	0.859	0.924	0.887	0.908

Rule Curve 58h 1169-1140 rise beginning April1. Winter Production-105000MWH

Results


0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
WY04
WY05
WY06
WY07
WY08
WY09
Actual
Maximum Production
Maximum Winter Production
Rule Curve 58h

Questions