MOSES LAKE
TOTAL MAXIMUM DAILY LOAD
PHOSPHORUS STUDY

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Environmental Assessment Program

What is this TMDL water quality study about? And why phosphorus?

Requirements for primary productivity (=algae growth)

- Light
- Warm temperatures
- Food (nutrients: carbon, nitrogen, phosphorus, micro-nutrients)

The Limiting Nutrient

Phytoplankton stochiometry

(of a typical algal cell) :

$\text{Carbon}_{106}\ \text{Hydrogen}_{263}\ \text{Oxygen}_{110}$
$\text{Nitrogen}_{16}\ \text{Phosphorus}_{1}$

Summary of Historical Studies

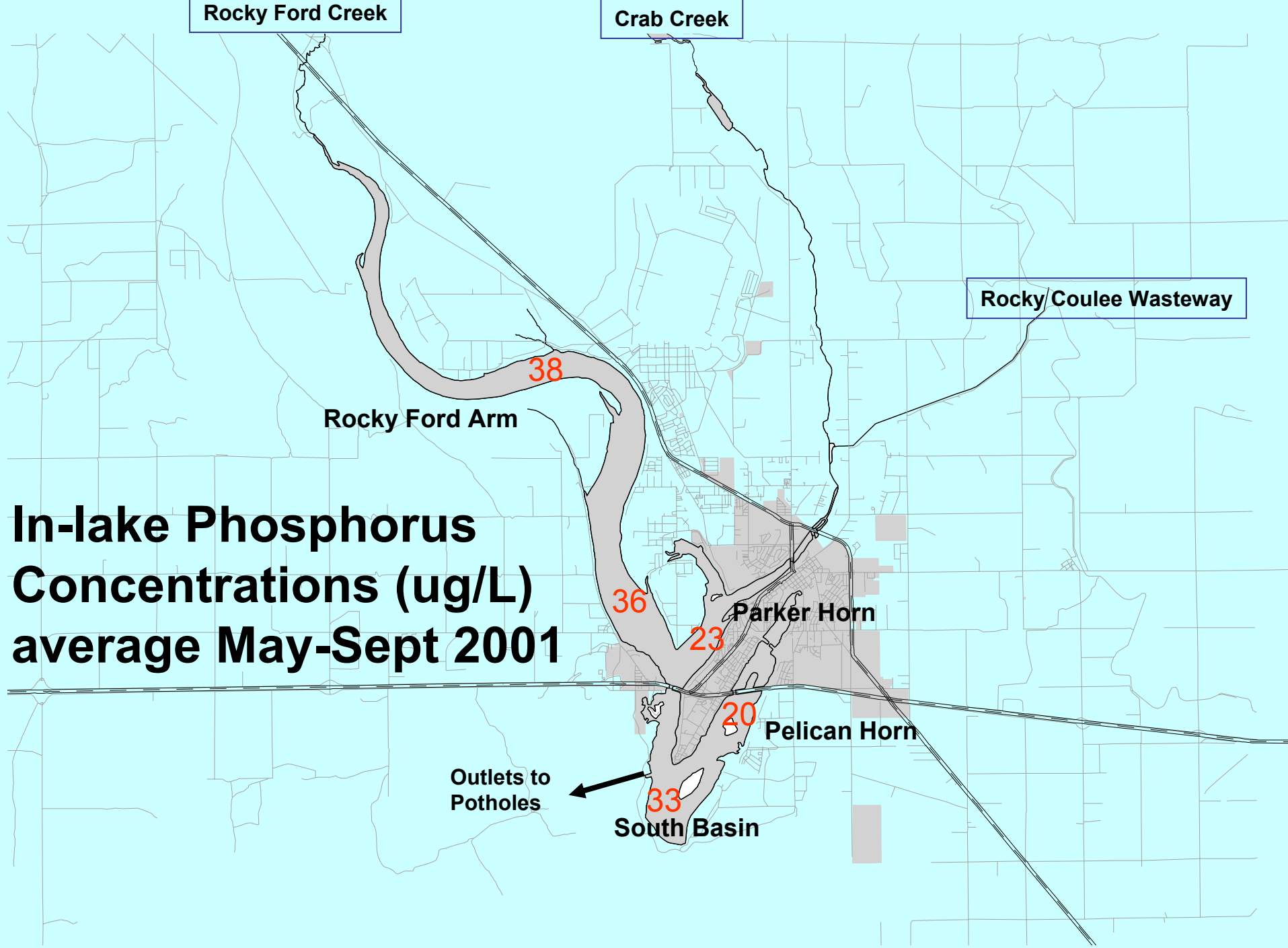
- Phosphorus is the nutrient to control
- Maximum in-lake phosphorus criterion of 50 ug/L may be appropriate for Moses Lake
- Successful restoration measures:
  - Moses Lake WWTP diversion in 1984
  - Dilution of Moses Lake with Columbia River water since late 1970s

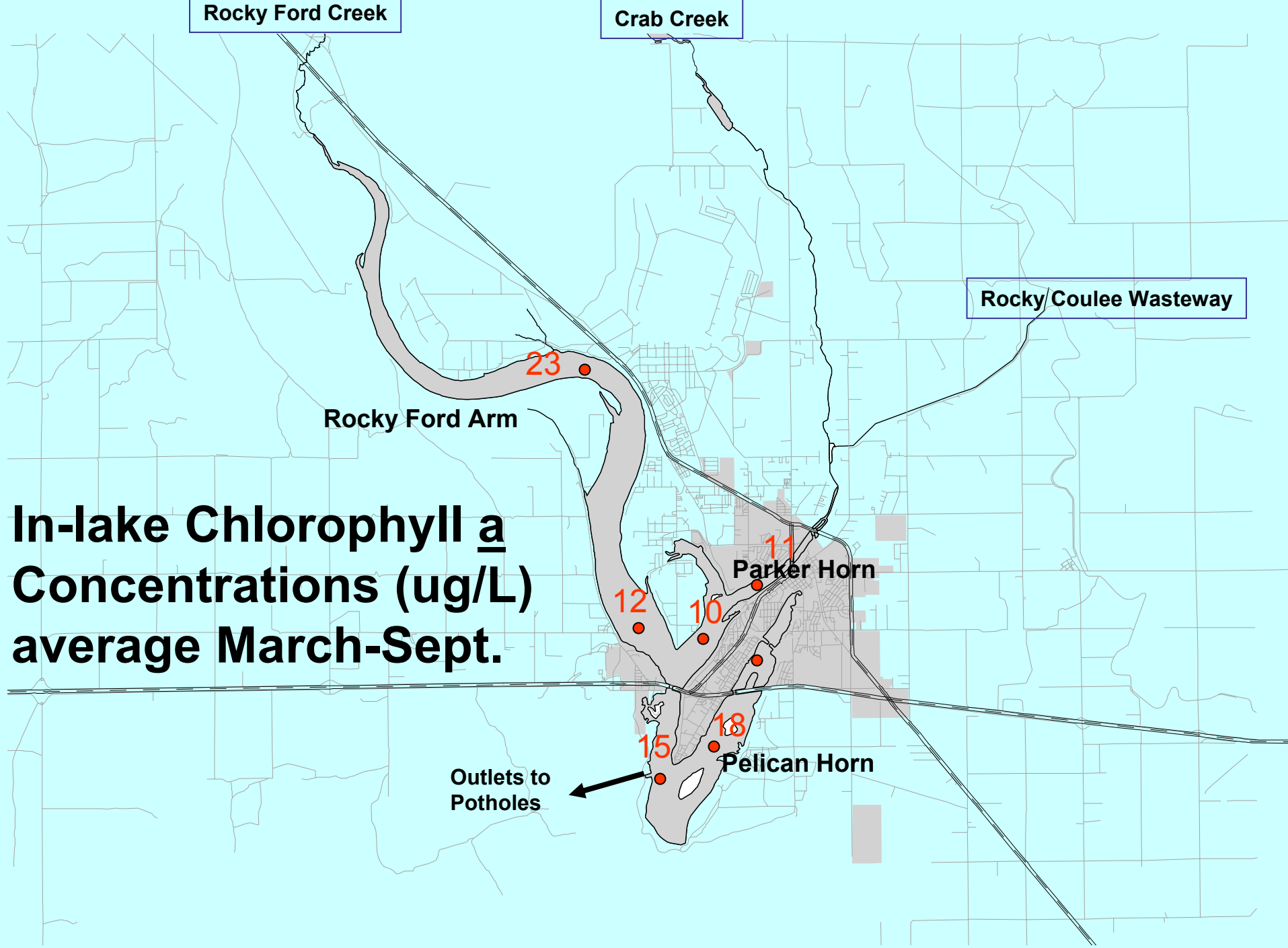
Need for New Assessment to Set Allocations for TMDL

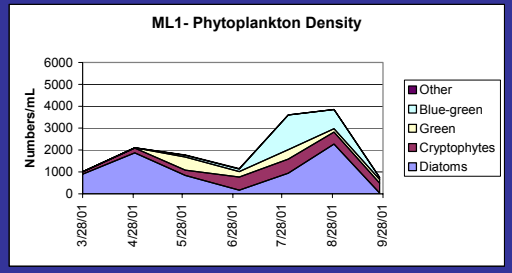
- Still have years with high phosphorus and blue-green algae
- Last intensive survey done in mid-1980s
- Restoration measures applied since then

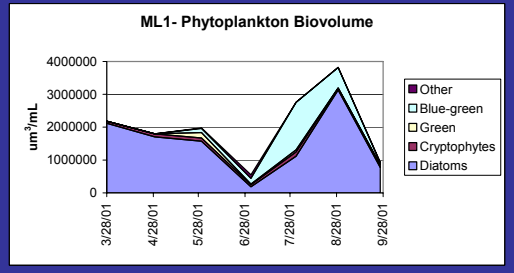
2001 Study Objectives

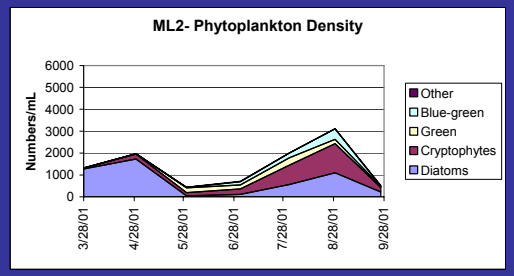
- Assess current water quality conditions
- Complete current lake water and phosphorus budget
- Develop model to assess the capacity of Moses Lake to assimilate phosphorus

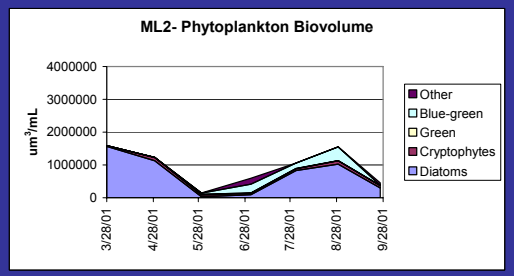

Rocky Ford Creek
Crab Creek
Rocky Coulee Wasteway
38
Rocky Ford Arm
In-lake Phosphorus Concentrations (ug/L) average May-Sept 2001
36
Parker Horn
23
20
Pelican Horn
Outlets to Potholes
33
South Basin

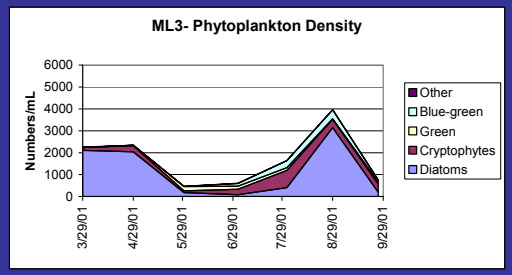

Rocky Ford Creek
Crab Creek
Rocky Coulee Wasteway
23
Rocky Ford Arm
In-lake Chlorophyll a
Concentrations (ug/L)
average March-Sept.
11
Parker Horn
12
10
18
15
Pelican Horn
Outlets to
Potholes

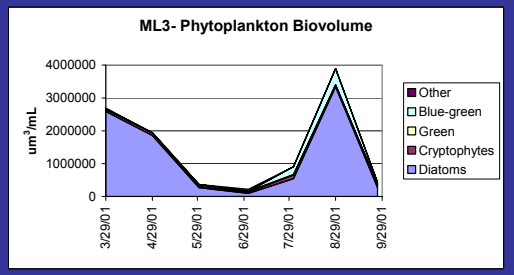

ML1- Phytoplankton Density
Numbers/mL
6000
5000
4000
3000
2000
1000
0
3/28/01
4/28/01
5/28/01
6/28/01
7/28/01
8/28/01
9/28/01
Other
Blue-green
Green
Cryptophytes
Diatoms

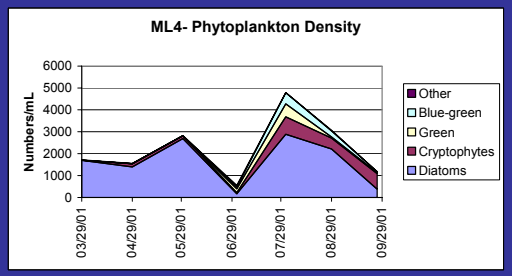

ML1- Phytoplankton Biovolume
um3/mL
4000000
3000000
2000000
1000000
0
3/28/01
4/28/01
5/28/01
6/28/01
7/28/01
8/28/01
9/28/01
Other
Blue-green
Green
Cryptophytes
Diatoms

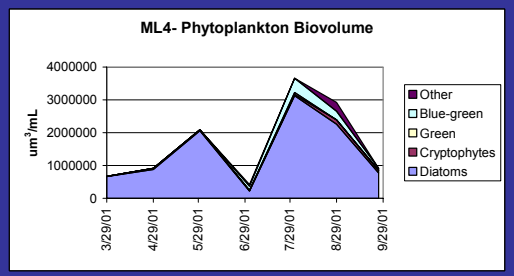

ML2- Phytoplankton Density
Numbers/mL
6000
5000
4000
3000
2000
1000
0
3/28/01
4/28/01
5/28/01
6/28/01
7/28/01
8/28/01
9/28/01
Other
Blue-green
Green
Cryptophytes
Diatoms

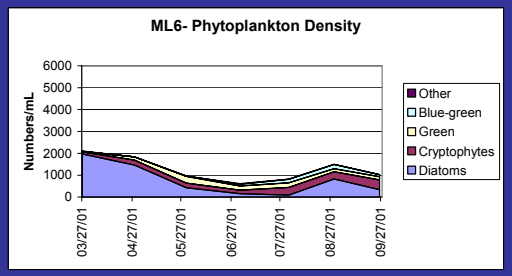

ML2- Phytoplankton Biovolume
um3/mL
4000000
3000000
2000000
1000000
0
3/28/01
4/28/01
5/28/01
6/28/01
7/28/01
8/28/01
9/28/01
Other
Blue-green
Green
Cryptophytes
Diatoms

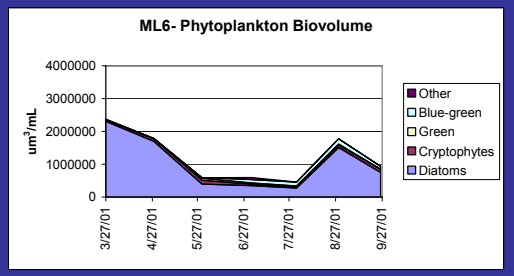

ML3- Phytoplankton Density
Numbers/mL
6000
5000
4000
3000
2000
1000
0
3/29/01
4/29/01
5/29/01
6/29/01
7/29/01
8/29/01
9/29/01
Other
Blue-green
Green
Cryptophytes
Diatoms


ML3- Phytoplankton Biovolume
um3/mL
4000000
3000000
2000000
1000000
0
3/29/01
4/29/01
5/29/01
6/29/01
7/29/01
8/29/01
9/29/01
Other
Blue-green
Green
Cryptophytes
Diatoms

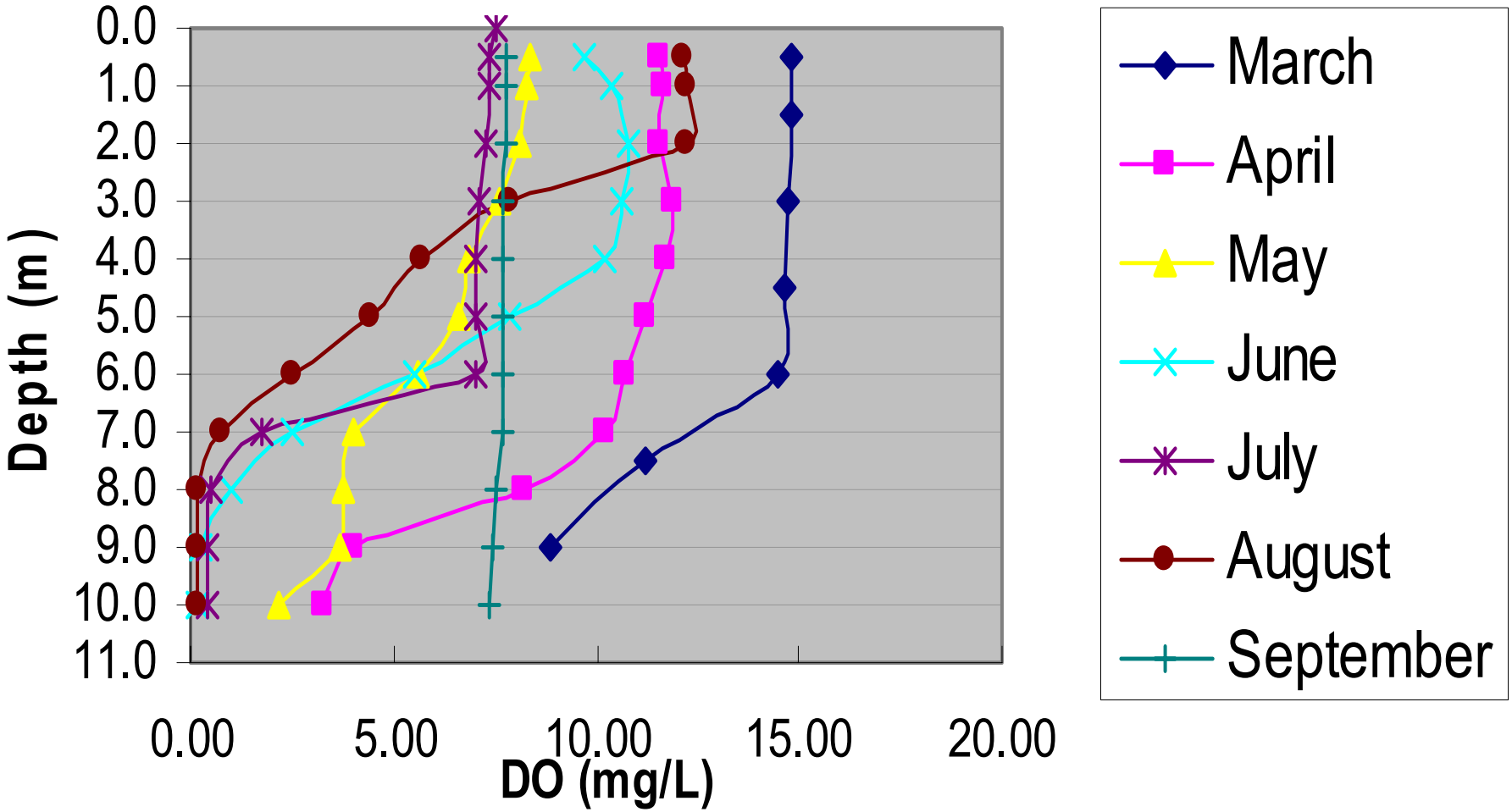

ML4- Phytoplankton Density
Numbers/mL
6000
5000
4000
3000
2000
1000
0
03/29/01
04/29/01
05/29/01
06/29/01
07/29/01
08/29/01
09/29/01
Other
Blue-green
Green
Cryptophytes
Diatoms


ML4- Phytoplankton Biovolume
um3/mL
4000000
3000000
2000000
1000000
0
3/29/01
4/29/01
5/29/01
6/29/01
7/29/01
8/29/01
9/29/01
Other
Blue-green
Green
Cryptophytes
Diatoms

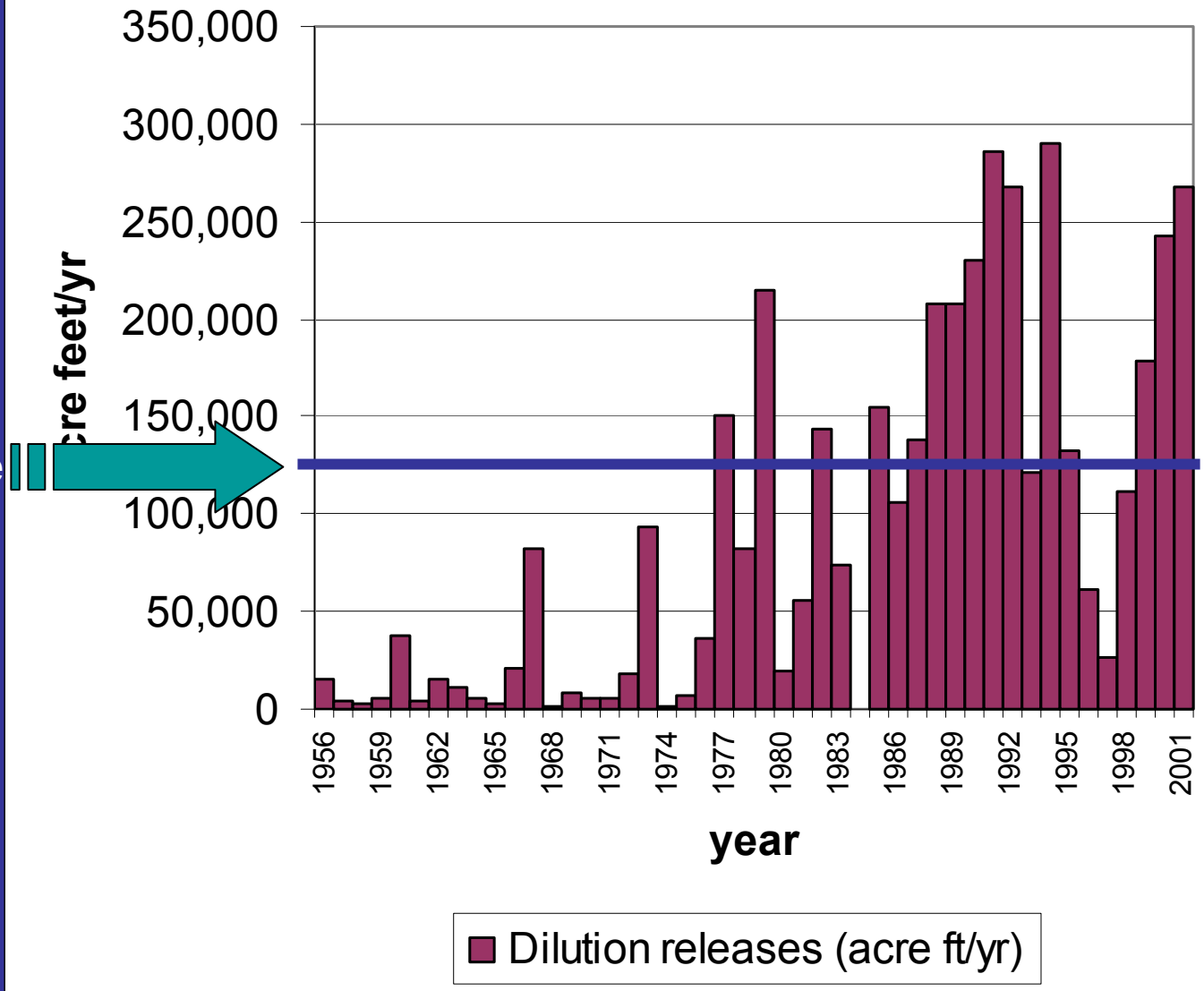

ML6- Phytoplankton Density
Numbers/mL
6000
5000
4000
3000
2000
1000
0
03/27/01
04/27/01
05/27/01
06/27/01
07/27/01
08/27/01
09/27/01
Other
Blue-green
Green
Cryptophytes
Diatoms


ML6- Phytoplankton Biovolume
um3/mL
4000000
3000000
2000000
1000000
0
3/27/01
4/27/01
5/27/01
6/27/01
7/27/01
8/27/01
9/27/01
Other
Blue-green
Green
Cryptophytes
Diatoms

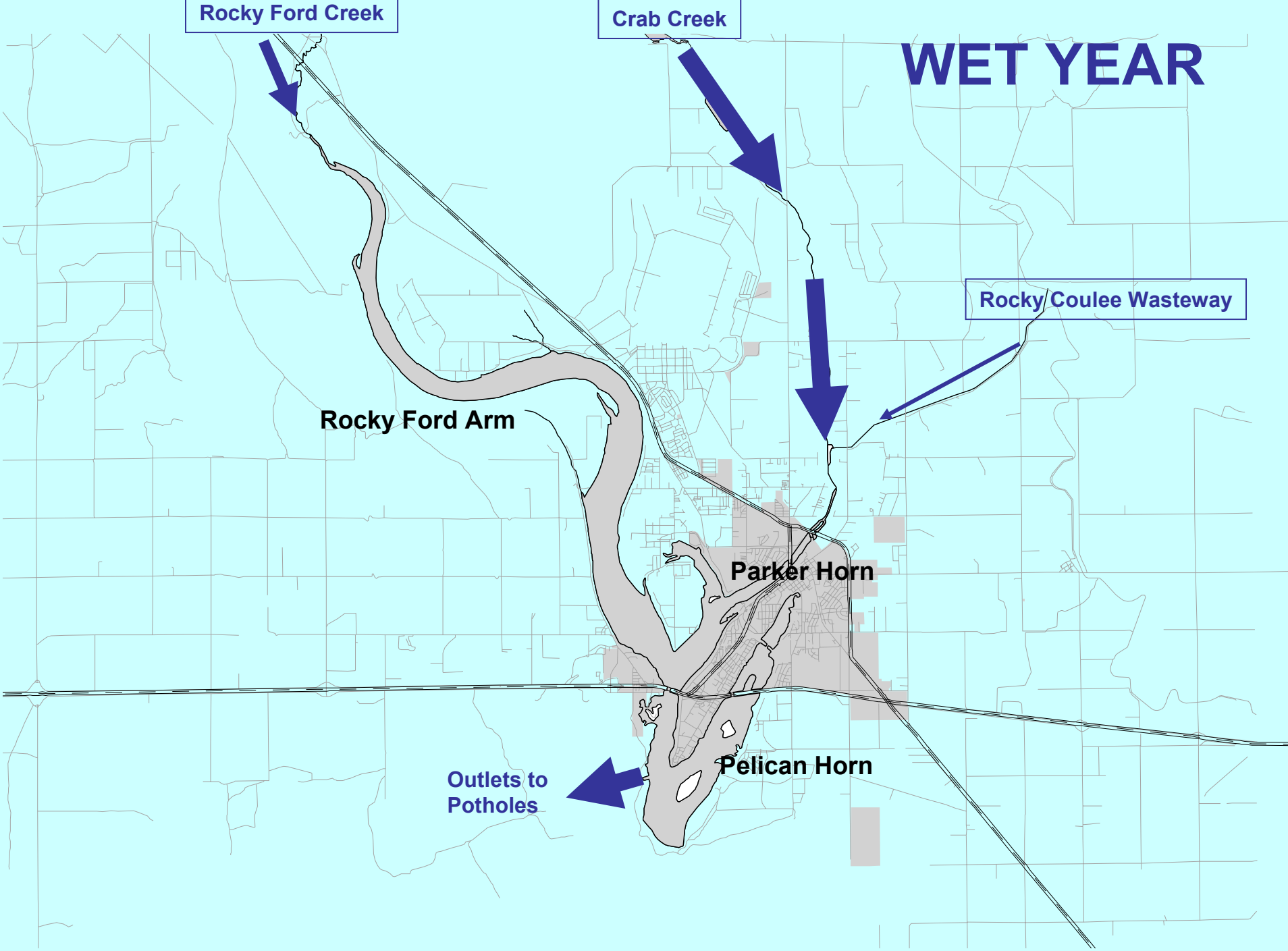
DO Profile

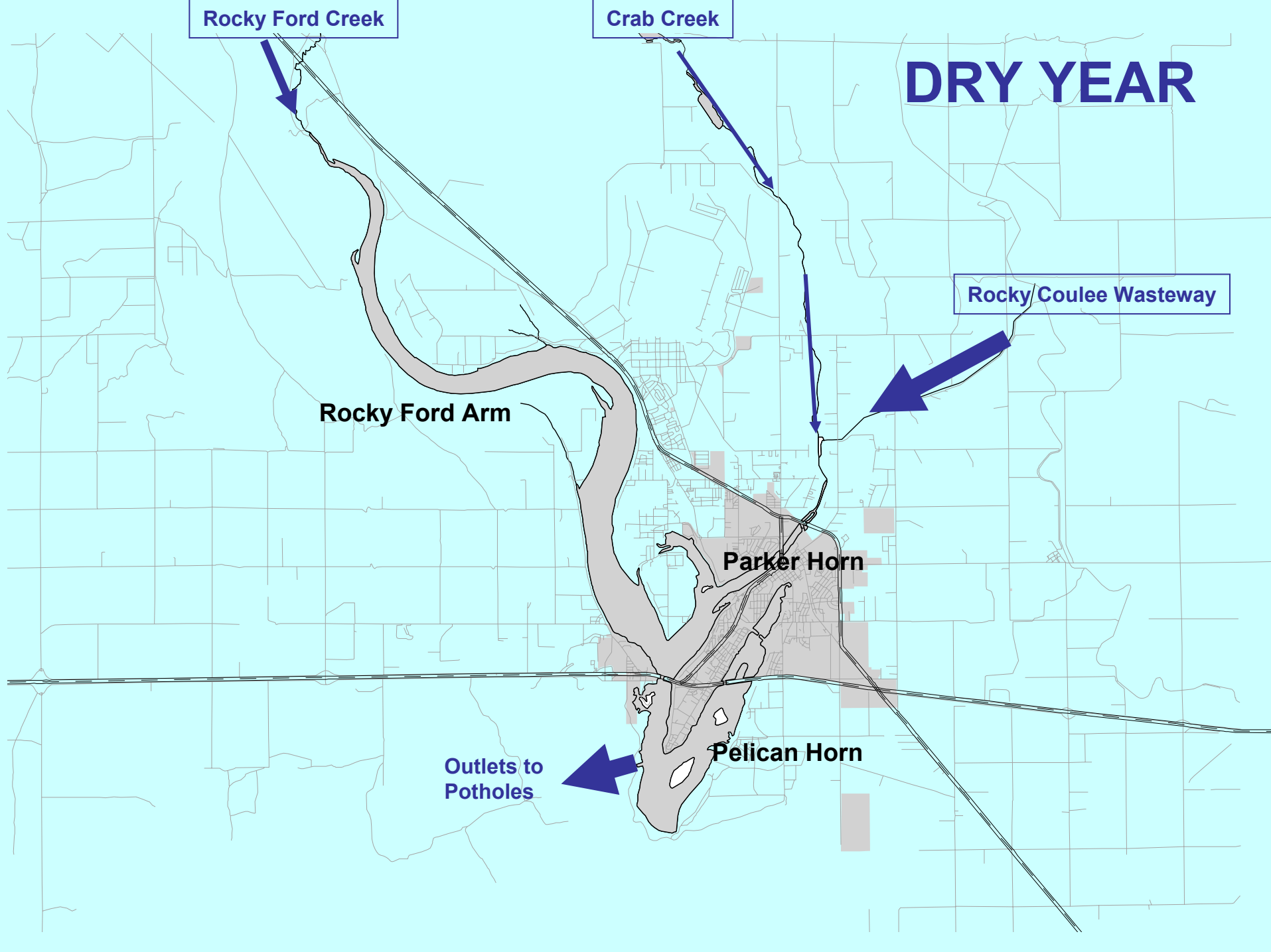

Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
0.00
5.00
10.00
15.00
20.00
DO (mg/L)
March
April
May
June
July
August
September

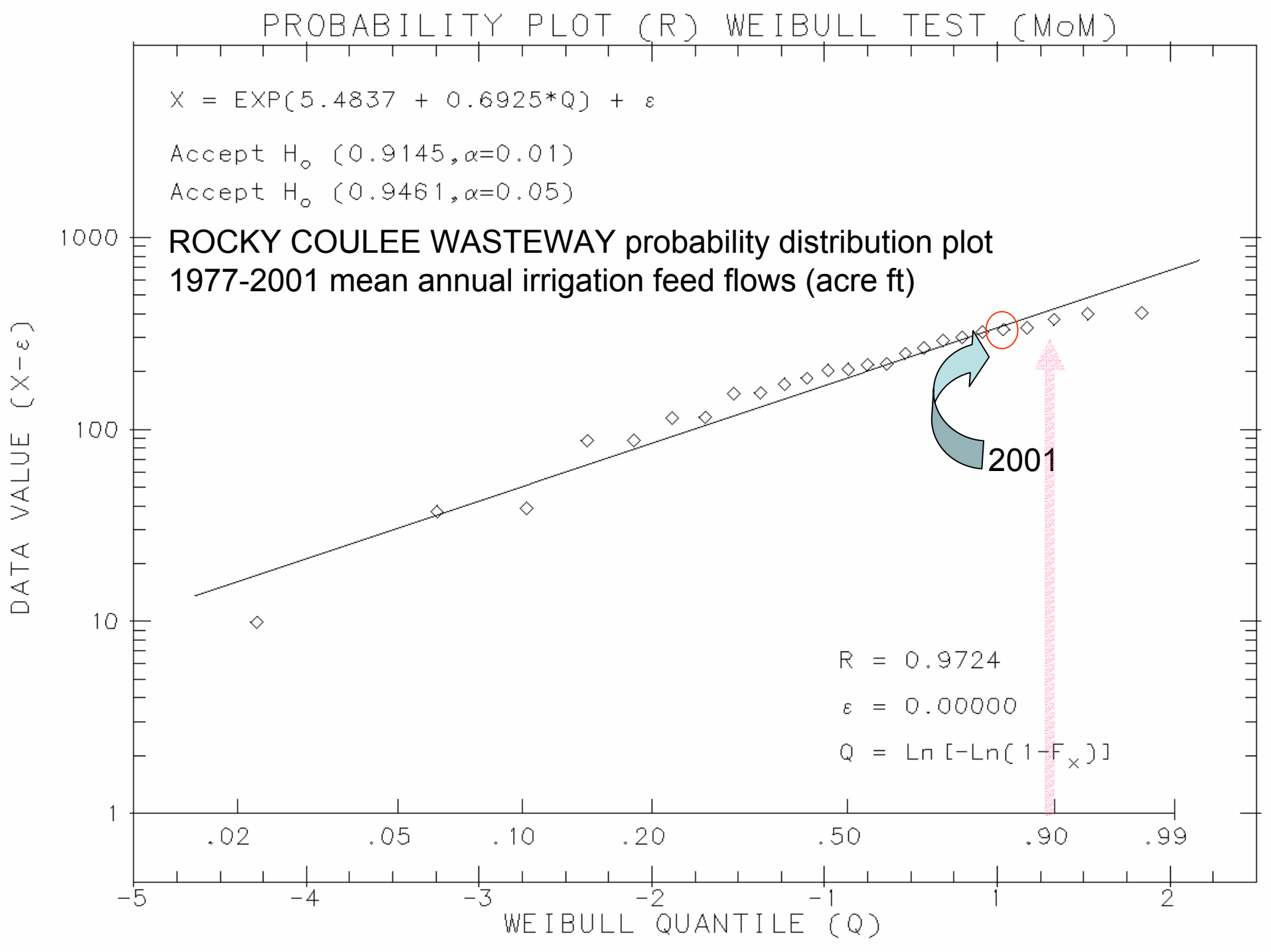
East Low Canal Releases to Moses Lake

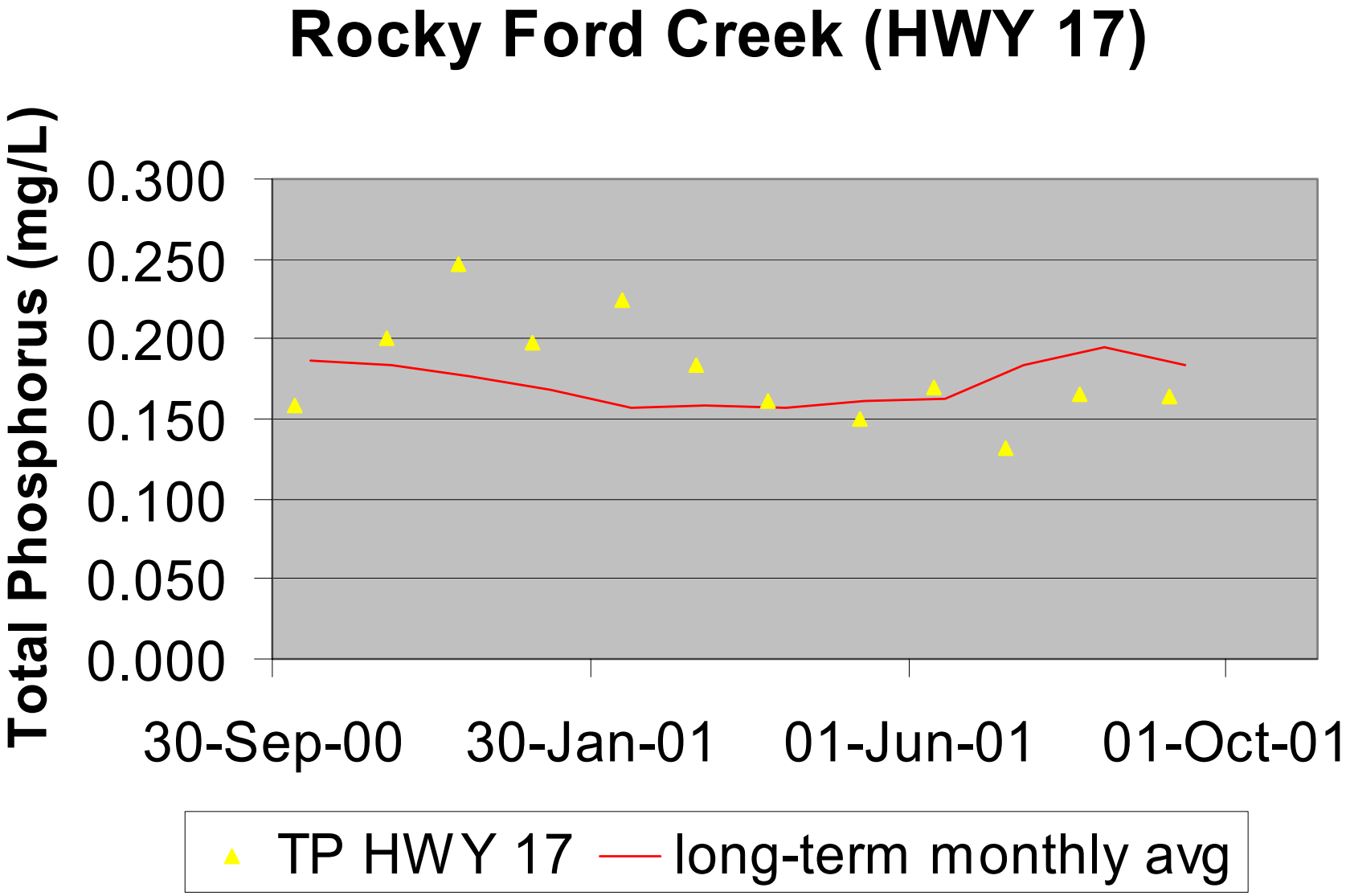


Moses Lake Volume = 125,000 acre feet

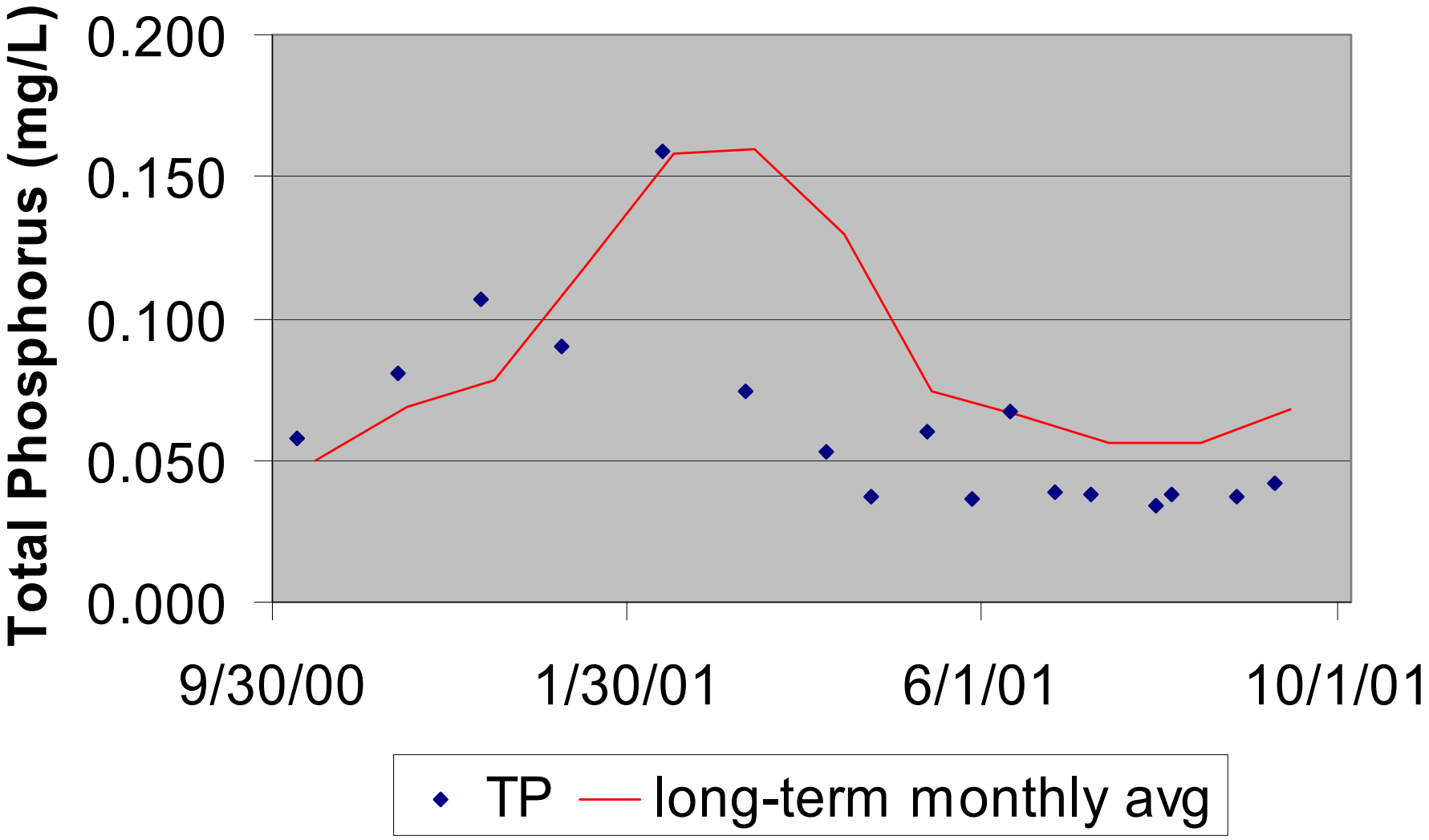

Rocky Ford Creek
Crab Creek
WET YEAR
Rocky Coulee Wasteway
Rocky Ford Arm
Parker Horn
Pelican Horn
Outlets to
Potholes

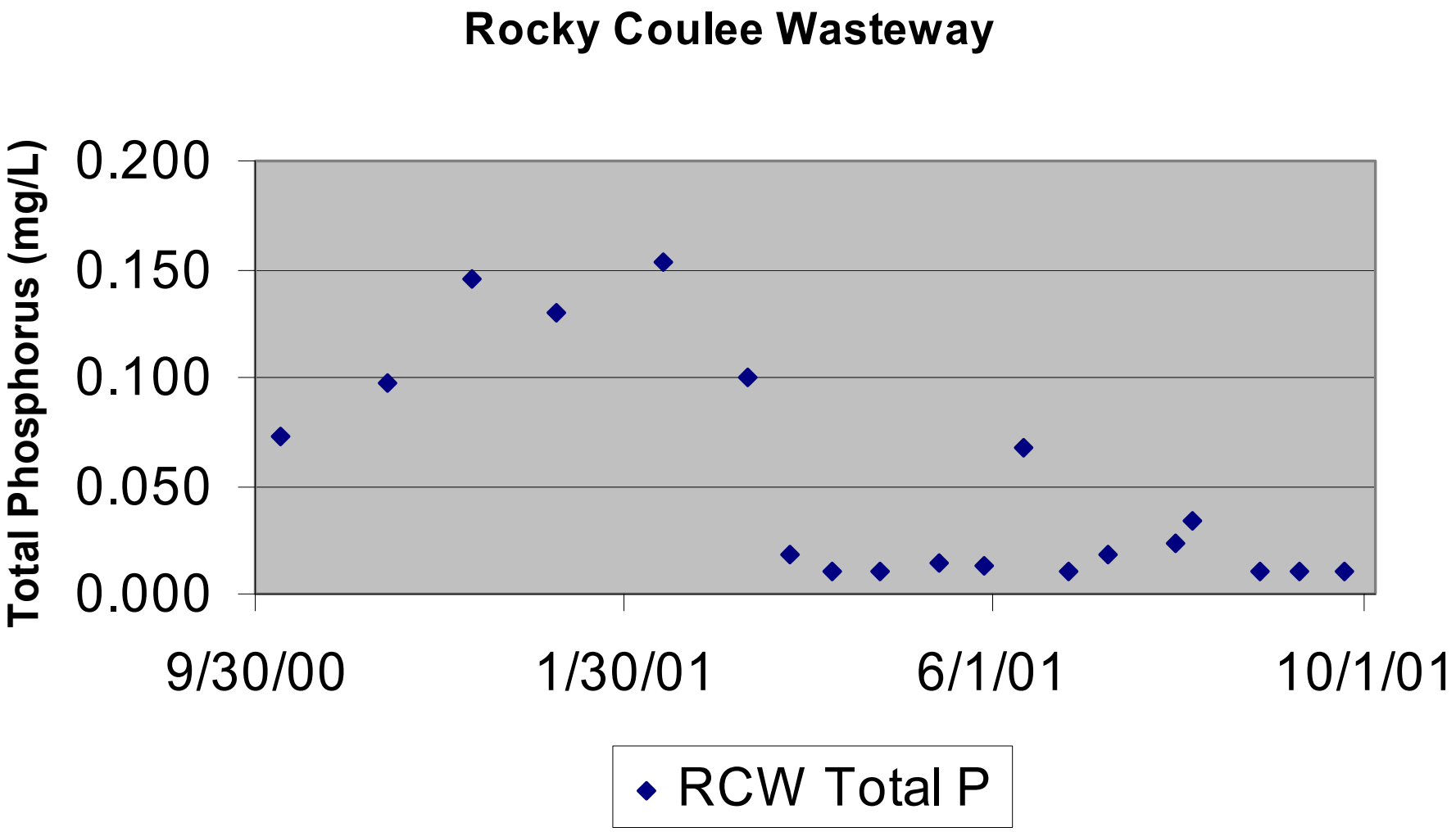

Rocky Ford Creek
Crab Creek
DRY YEAR
Rocky Coulee Wasteway
Rocky Ford Arm
Parker Horn
Pelican Horn
Outlets to
Potholes


PROBABILITY PLOT (R) WEIBULL TEST (MoM)
X = EXP(5.4837 + 0.6925*Q) + ε
Accept H₀ (0.9145, α=0.01)
Accept H₀ (0.9461, α=0.05)
ROCKY COULEE WASTEWAY probability distribution plot
1977-2001 mean annual irrigation feed flows (acre ft)
2001
R = 0.9724
ε = 0.00000
Q = Ln[-Ln(1-F_X)]
DATA VALUE (X-ε)
1000
100
10
1
.02
.05
.10
.20
.50
.90
.99
-5
-4
-3
-2
-1
1
2
WEIBULL QUANTILE (Q)


Rocky Ford Creek (HWY 17)
Total Phosphorus (mg/L)
0.300
0.250
0.200
0.150
0.100
0.050
0.000
30-Sep-00
30-Jan-01
01-Jun-01
01-Oct-01
TP HWY 17
long-term monthly avg

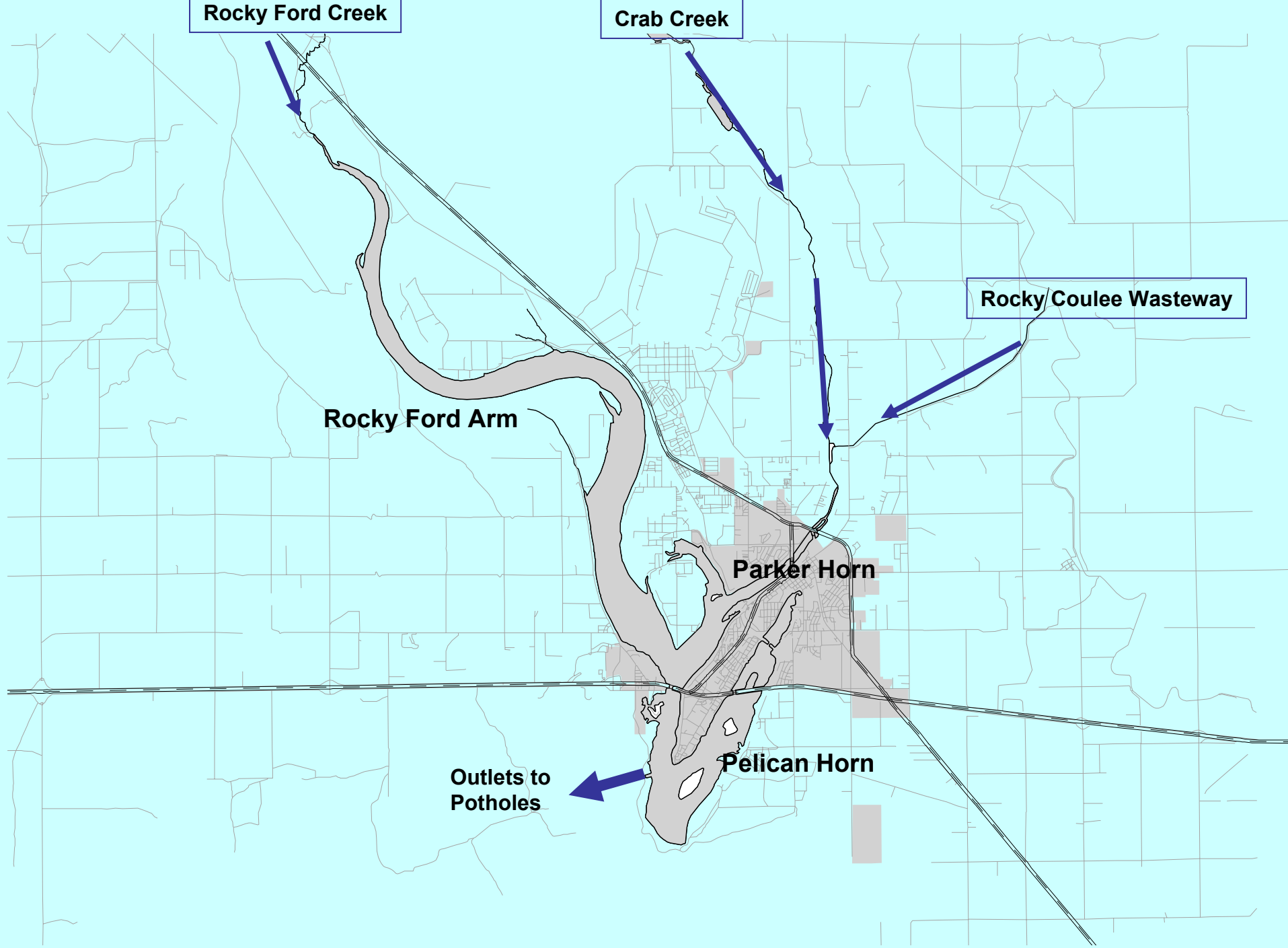
Crab Creek nr Moses Lake




Rocky Coulee Wasteway
Total Phosphorus (mg/L)
0.200
0.150
0.100
0.050
0.000
9/30/00
1/30/01
6/1/01
10/1/01
RCW Total P

2001 Study Objectives

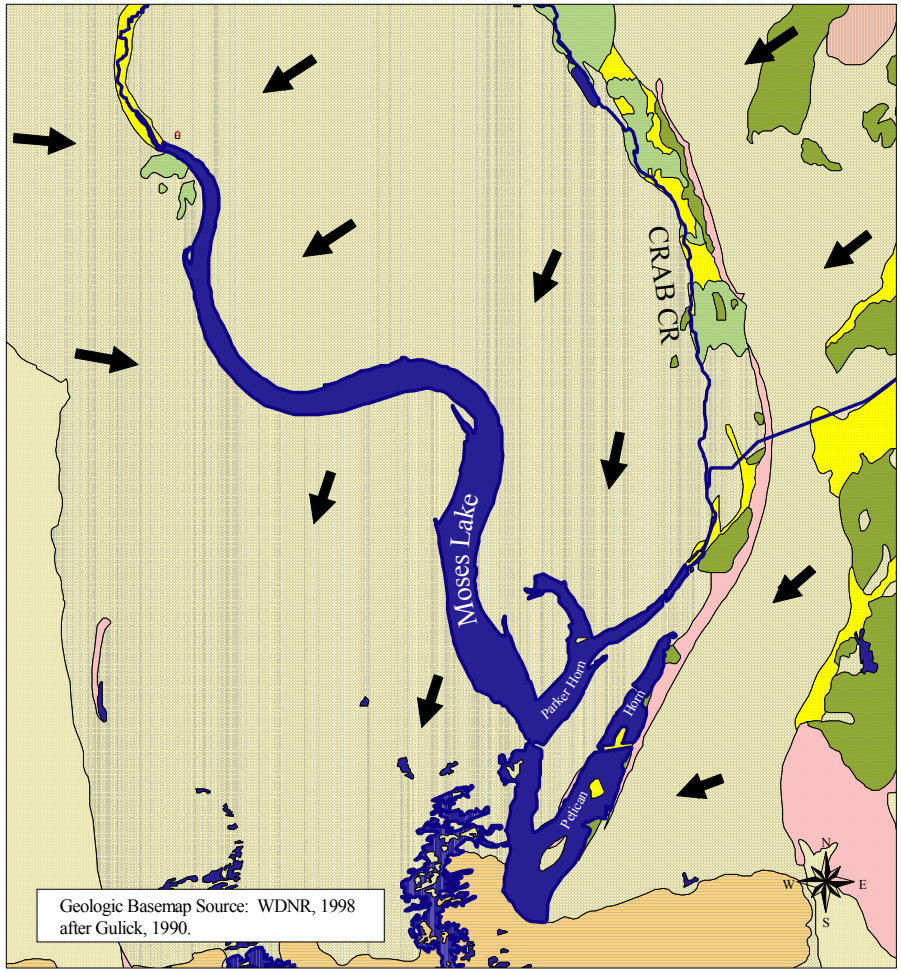
- Assess current water quality conditions
- Complete current lake water and phosphorus budget
- Develop model to assess the capacity of Moses Lake to assimilate phosphorus


Rocky Ford Creek
Crab Creek
Rocky Coulee Wasteway
Rocky Ford Arm
Parker Horn
Pelican Horn
Outlets to
Potholes

11/8/2001

11/8/2001

12/30/



Legend

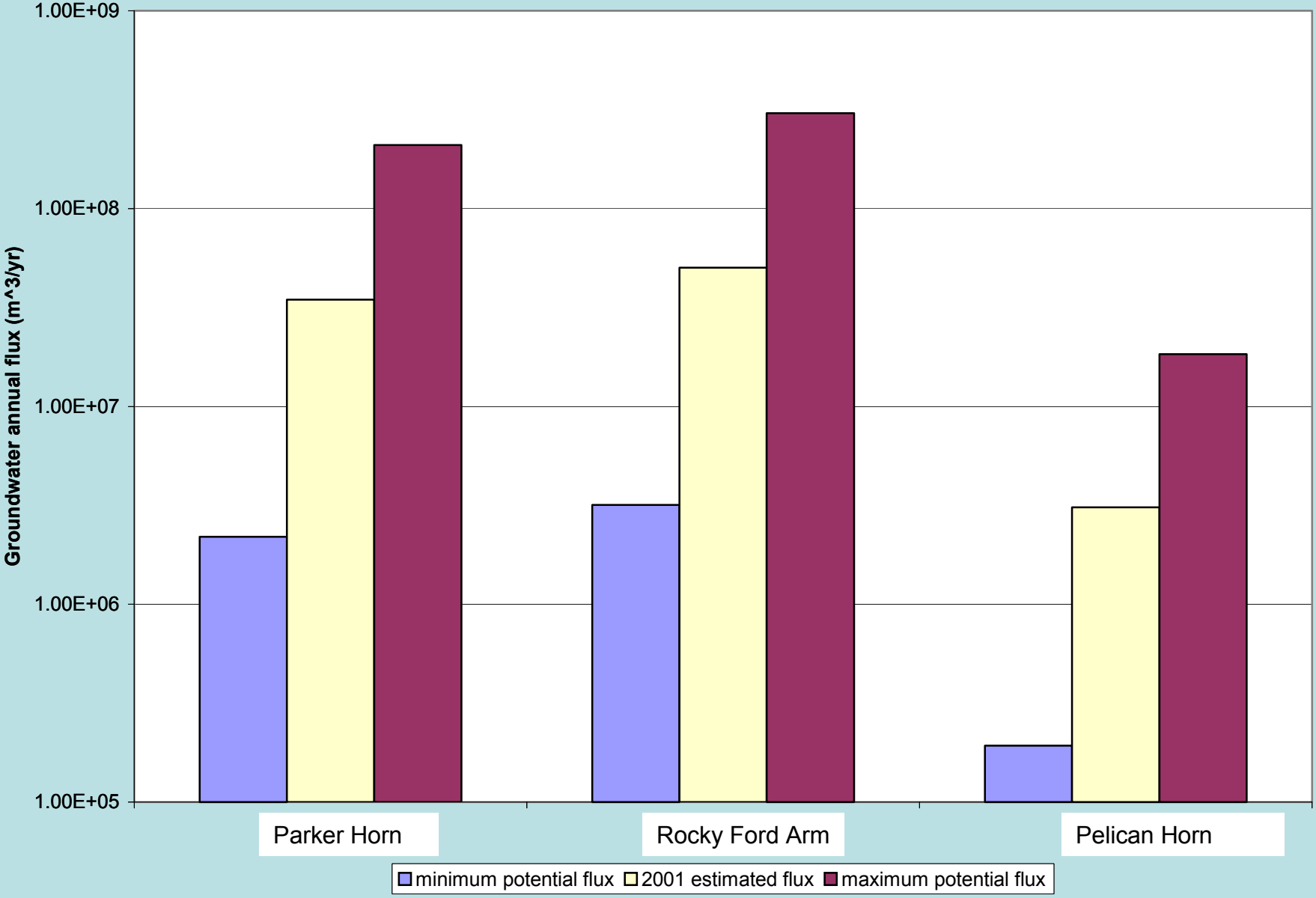
- Alluvium
- Loess
- Lacustrine deposits
- Pleistocene Flood Deposits (grvl)
- Pleistocene Flood Deposits (slt/snd)
- Ringold Formation
- Priest Rapids Wanapum
- Roza Wanapum
- Water

General Groundwater Flow Direction in Surficial Aquifer

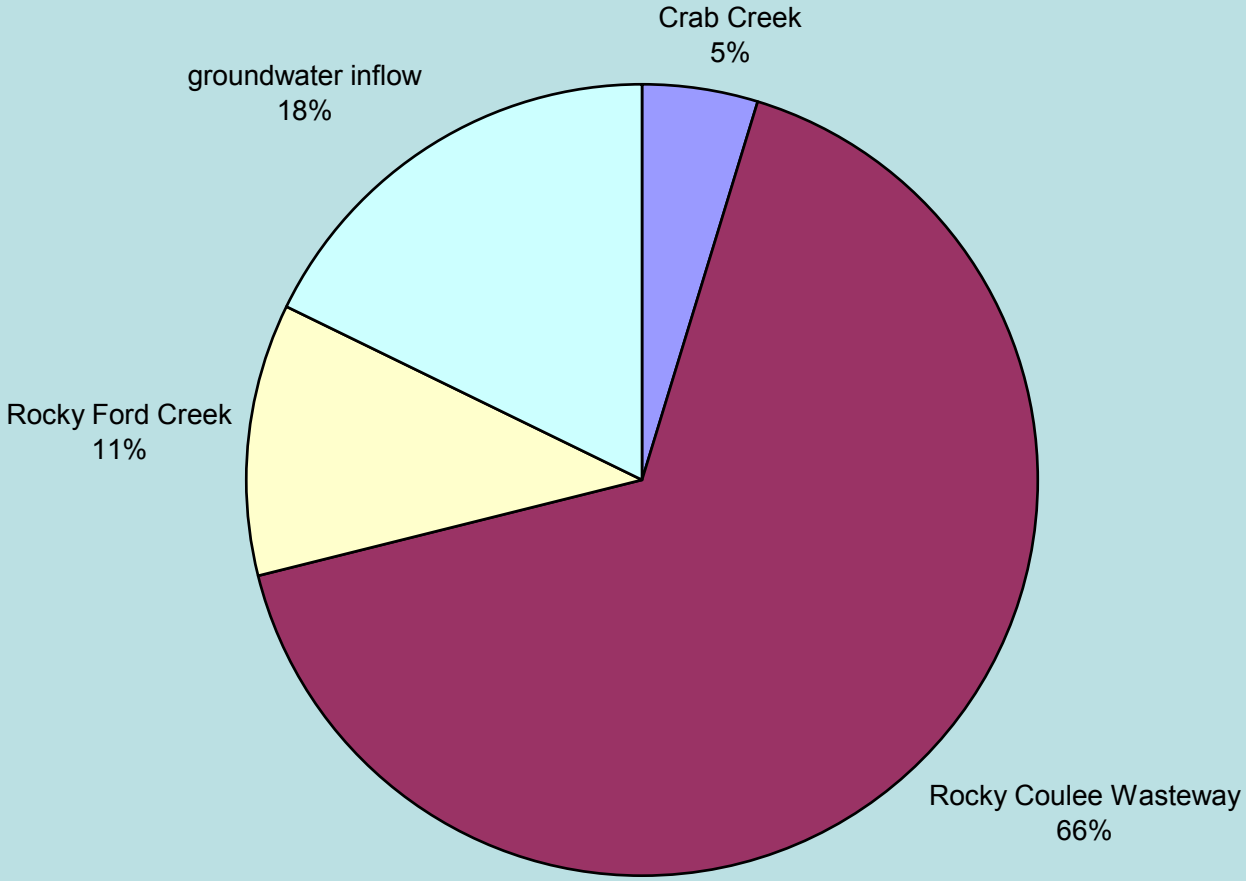
DRAFT

Figure 4 -
Surficial Geology Map
Moses Lake TMDL
Groundwater Study

1 0 1 2 Miles


1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
Groundwater annual flux (m^3/yr)
Parker Horn
Rocky Ford Arm
Pelican Horn
minimum potential flux
2001 estimated flux
maximum potential flux

Moses Lake inflows (Oct 2000 - Sept 2001)



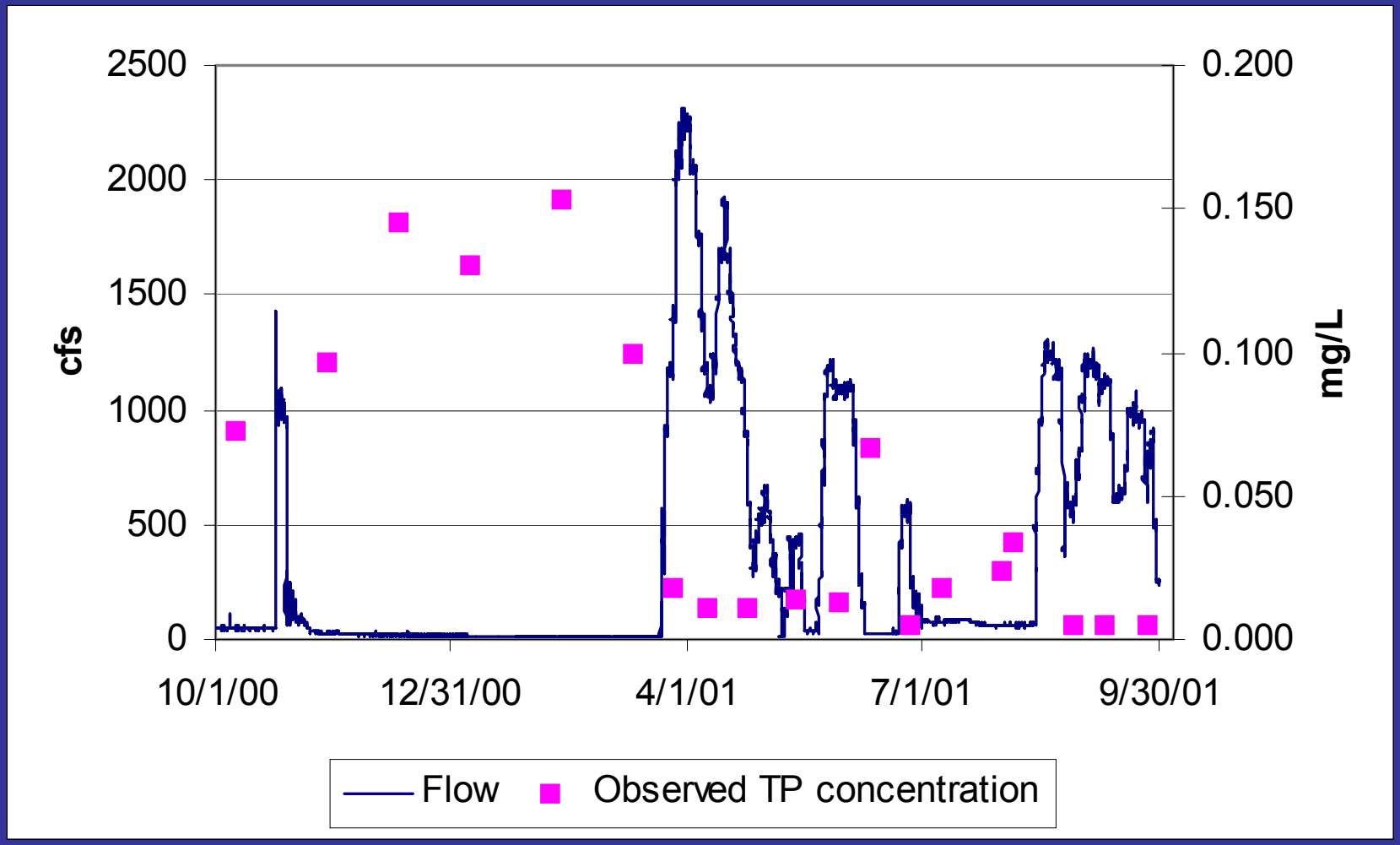
Phosphorus Budget for Moses Lake TMDL

Inputs of phosphorus (Rocky Ford Ck, Crab Ck, Rocky Coulee Wasteway, groundwater, resuspension from sediments)

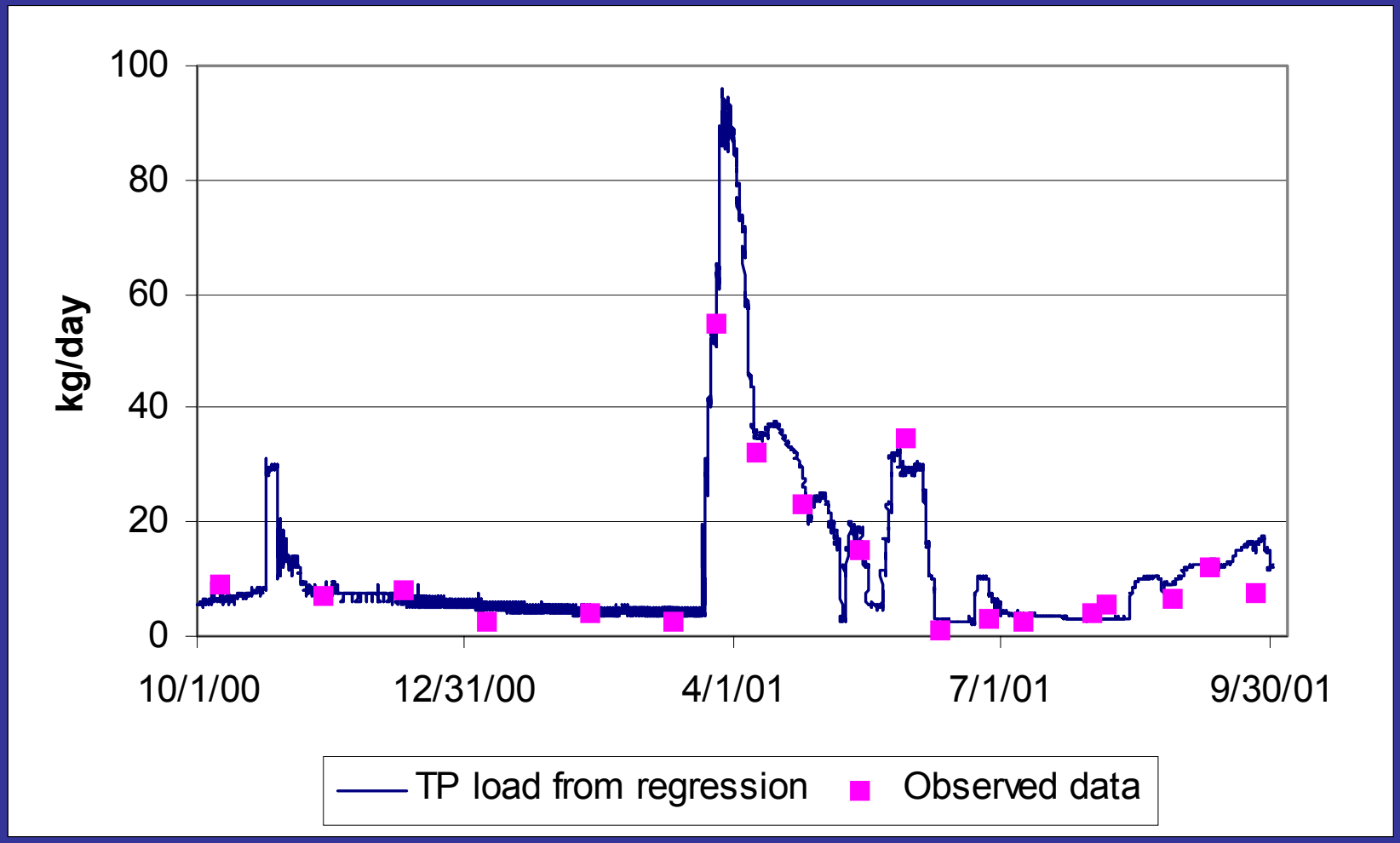
- Outputs of phosphorus (outlets, groundwater, phosphorus that settles to bottom)

= Phosphorus concentration left in the water column to grow algae

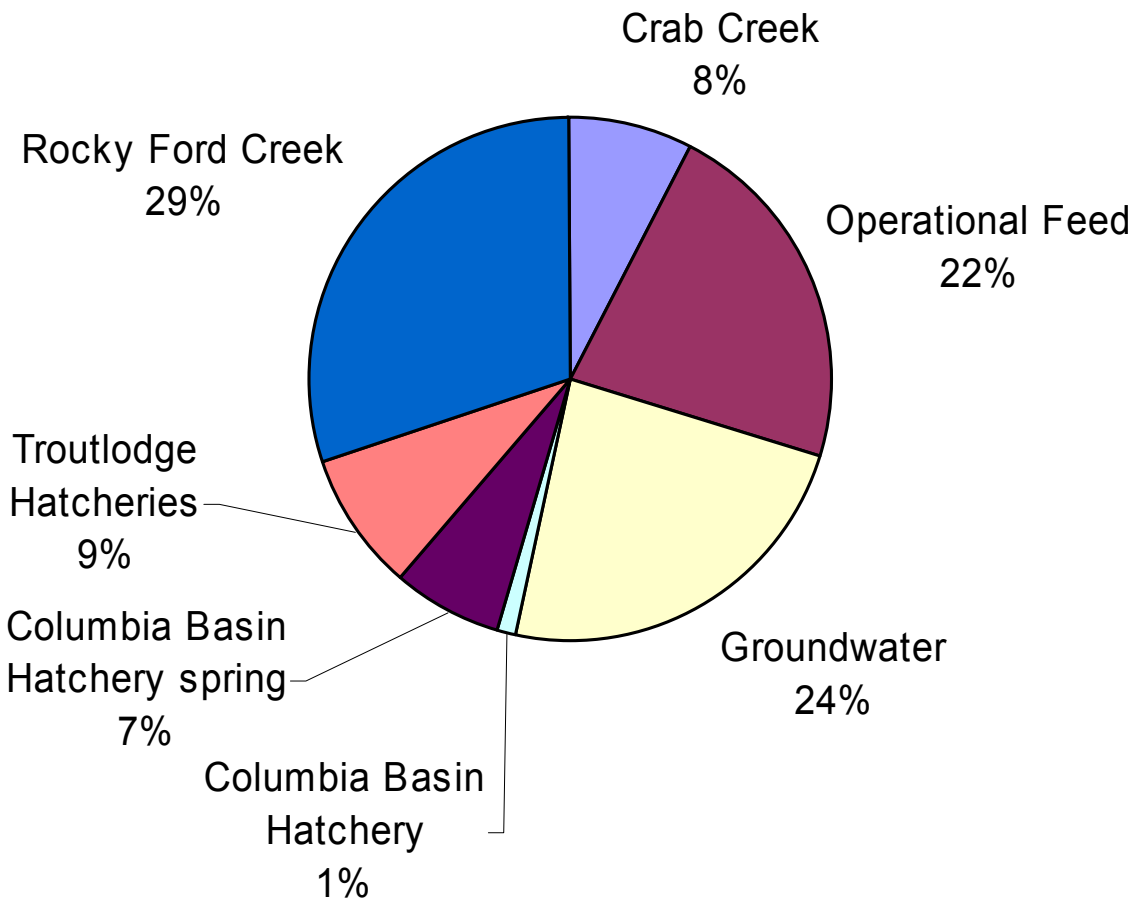
Rocky Coulee Wasteway



Rocky Coulee Wasteway



May to Sept 2001 TP load contribution to Moses Lake



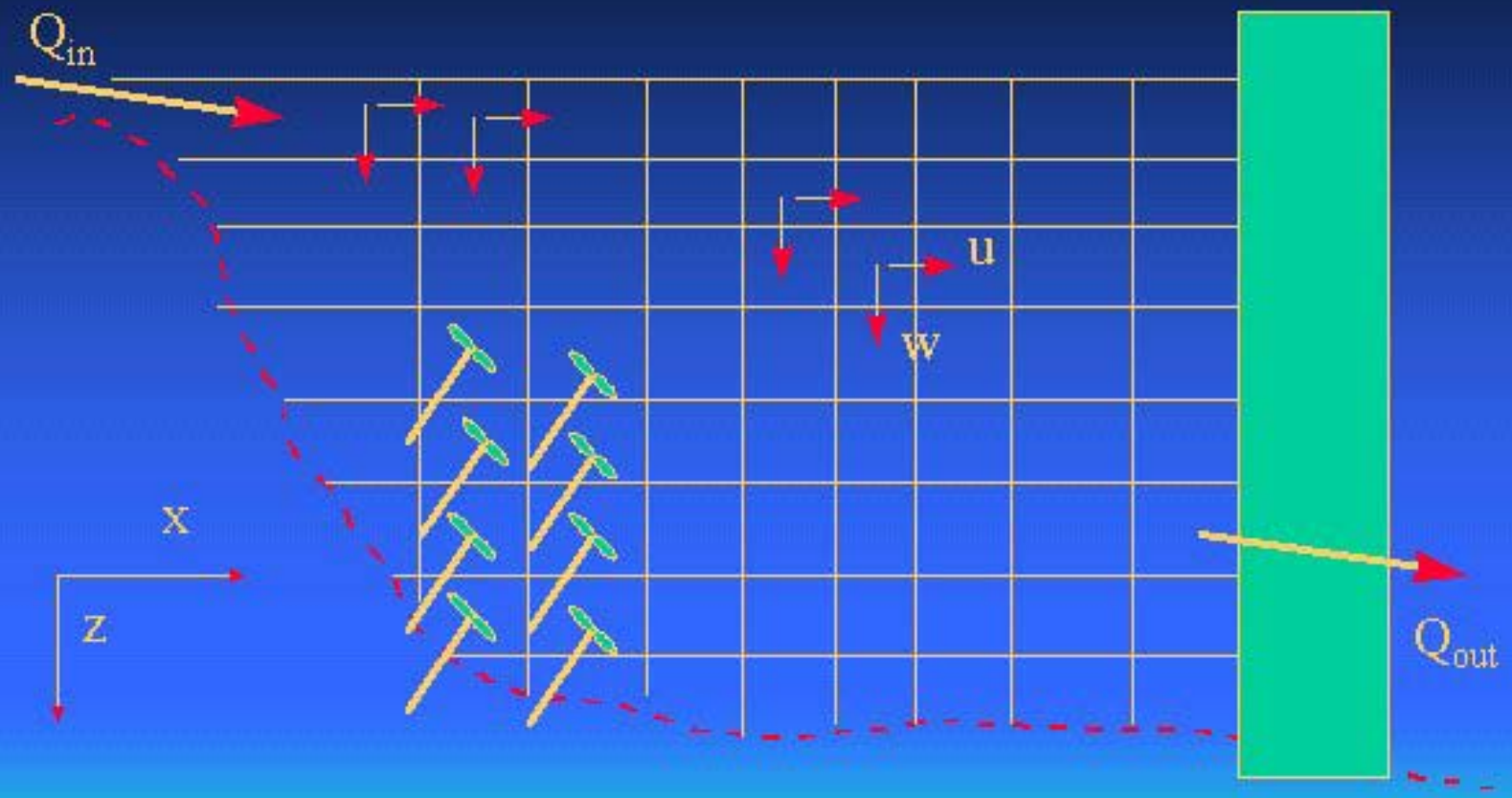
2001 Study Objectives

- Assess current water quality conditions
- Complete current lake water and phosphorus budget
- Develop model to assess the capacity of Moses Lake to assimilate phosphorus

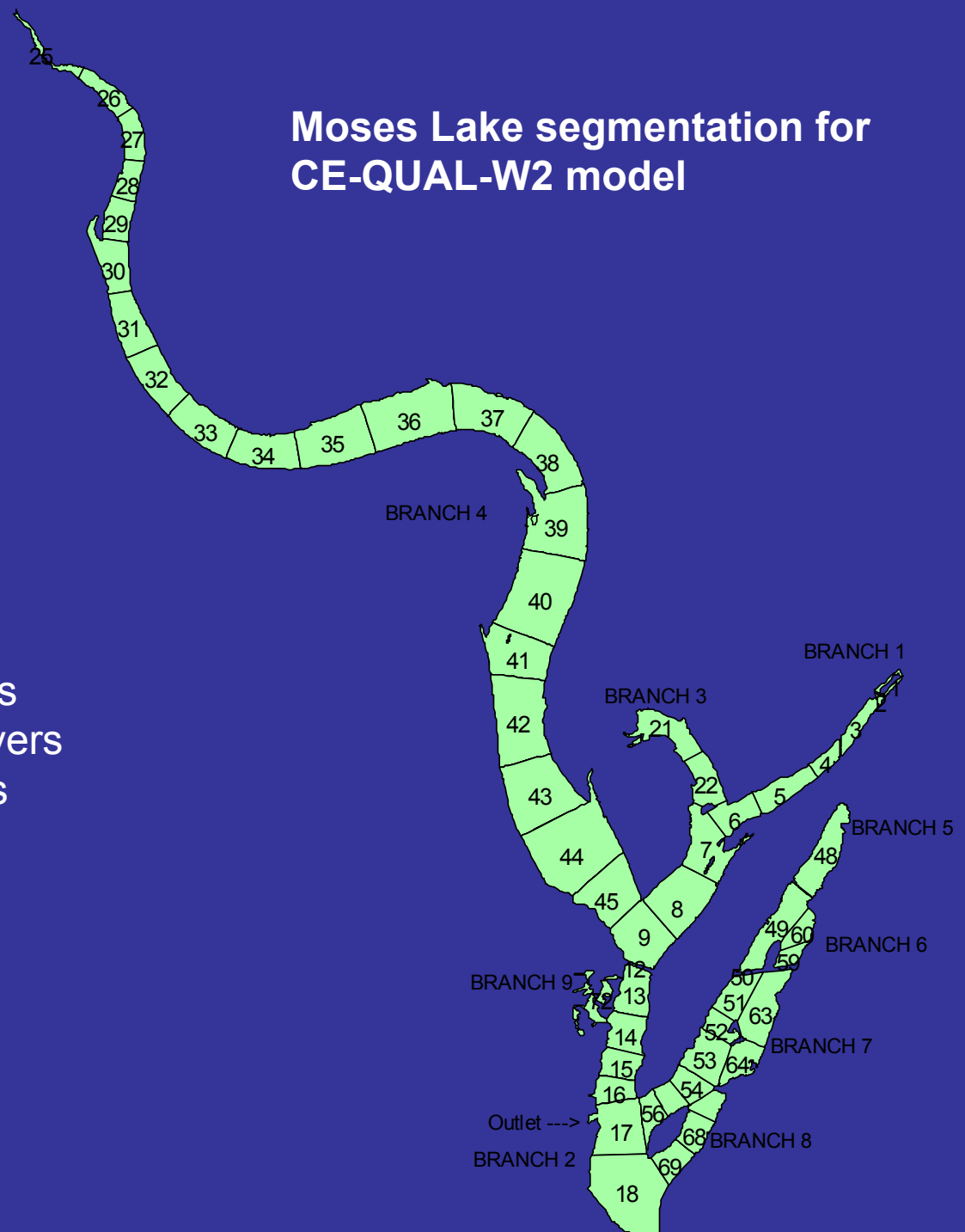
CE-QUAL-W2 Water Quality Model

Two-Dimensional Hydrodynamics: x-z model

Two-dimensional hydrodynamics



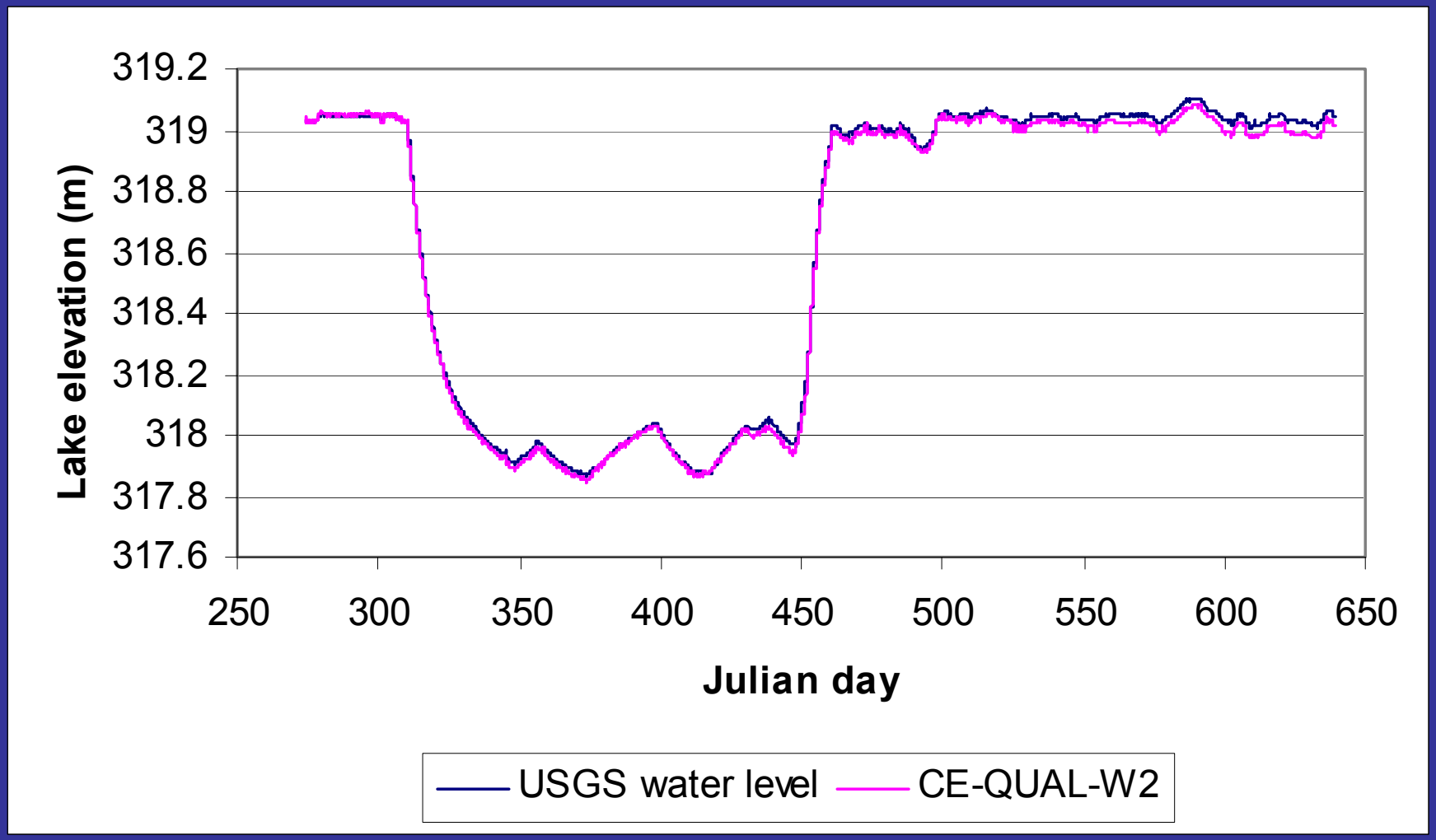
Moses Lake segmentation for CE-QUAL-W2 model



74 segments
12 depth layers
9 branches

Model Goals

- Develop an accurate water balance
- Simulate hydrodynamics of Moses Lake
- Calibrate 2000-01 phosphorus loads to Moses Lake with observed in-lake phosphorus concentrations
- Model in-lake phosphorus concentrations for a critical phosphorus loading year and use model as a management tool for phosphorus reduction


319.2
319
318.8
318.6
318.4
318.2
318
317.8
317.6
Lake elevation (m)
250
300
350
400
450
500
550
600
650
Julian day
USGS water level
CE-QUAL-W2

Model Goals

- Develop an accurate water balance
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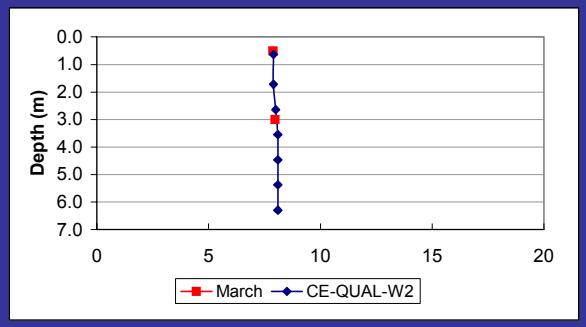
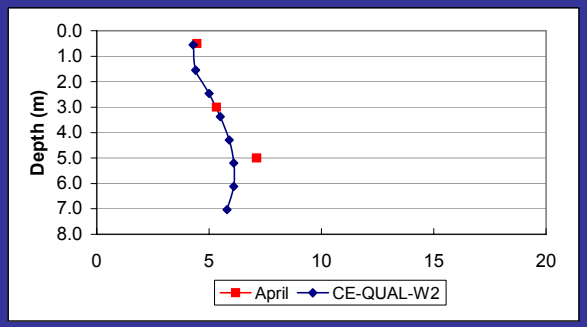
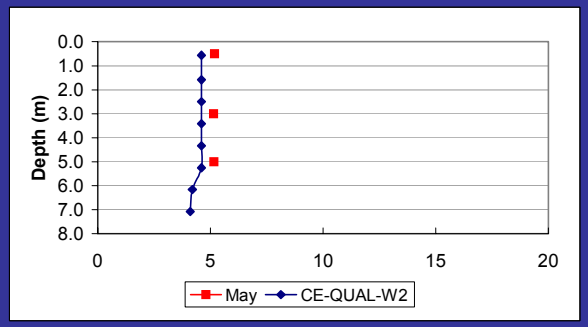
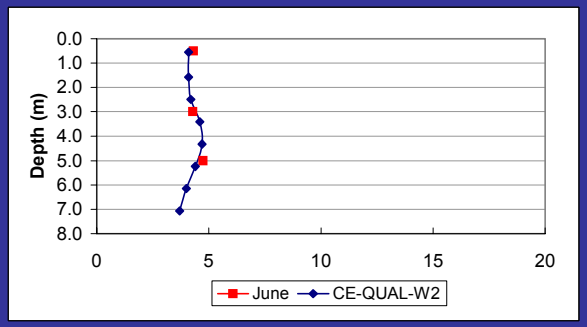
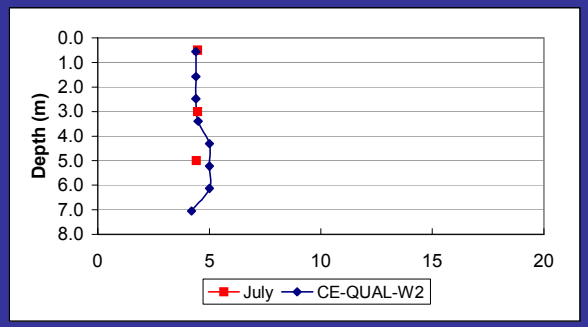
- Calibrate 2000-01 phosphorus loads to Moses Lake with observed in-lake phosphorus concentrations
- Model in-lake phosphorus concentrations for a critical phosphorus loading year and use model as a management tool for phosphorus reduction

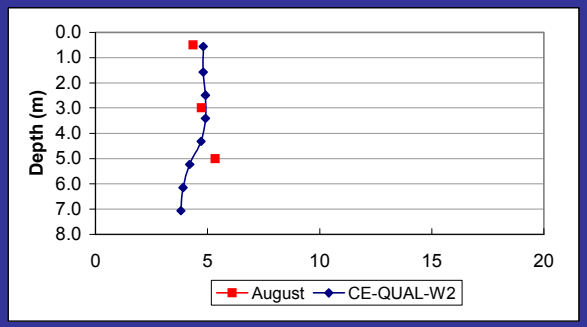

Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0
5
10
15
20
March
CE-QUAL-W2

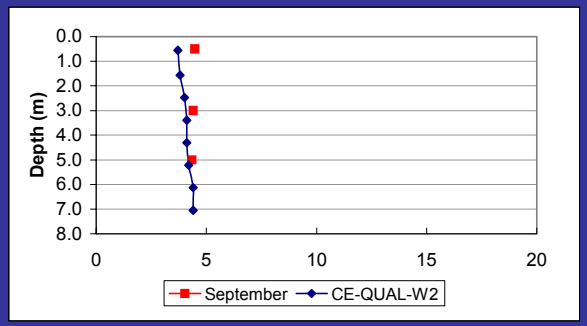

Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
0
5
10
15
20
April
CE-QUAL-W2


Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
0
5
10
15
20
May
CE-QUAL-W2


Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
0
5
10
15
20
June
CE-QUAL-W2


Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
0
5
10
15
20
July
CE-QUAL-W2


Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
0
5
10
15
20
August
CE-QUAL-W2


Depth (m)
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2.0
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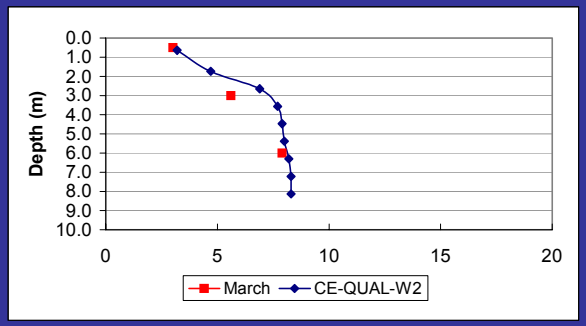
15
20
September
CE-QUAL-W2

Station 1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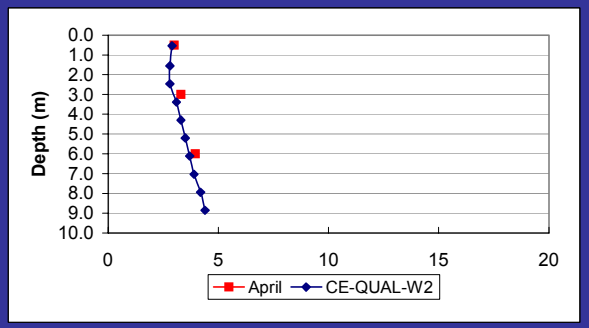
20
March
CE-QUAL-W2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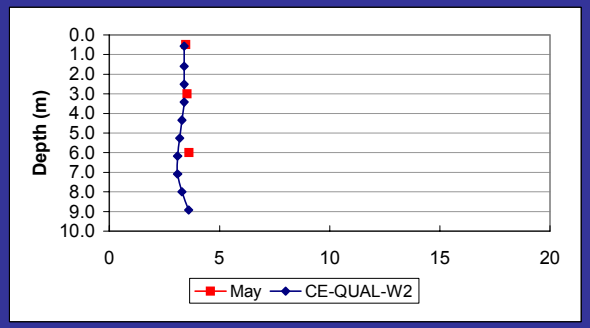
20
April
CE-QUAL-W2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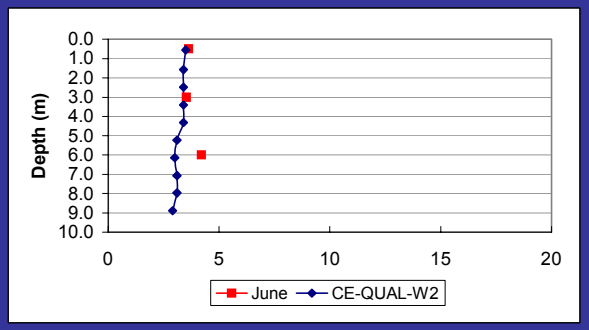
May
CE-QUAL-W2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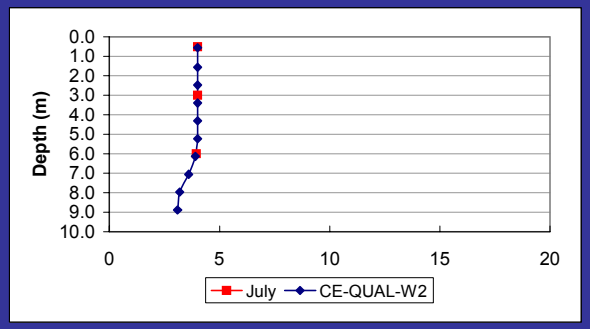
June
CE-QUAL-W2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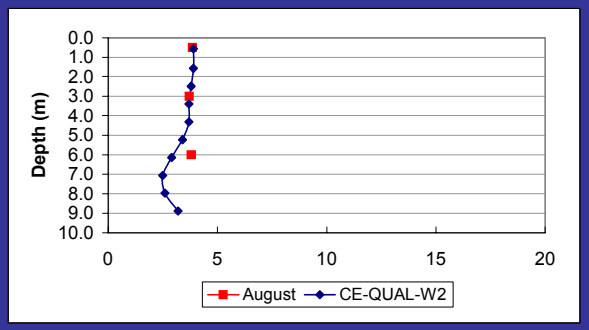
20
July
CE-QUAL-W2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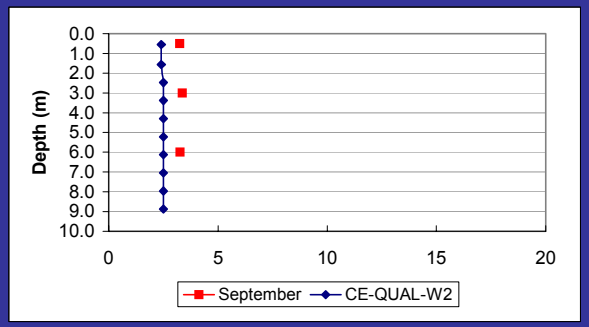
August
CE-QUAL-W2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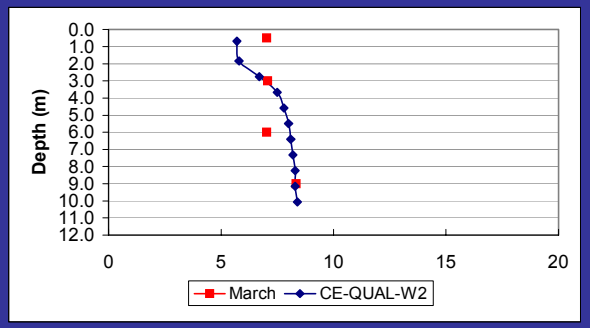
10
15
20
September
CE-QUAL-W2

Station 2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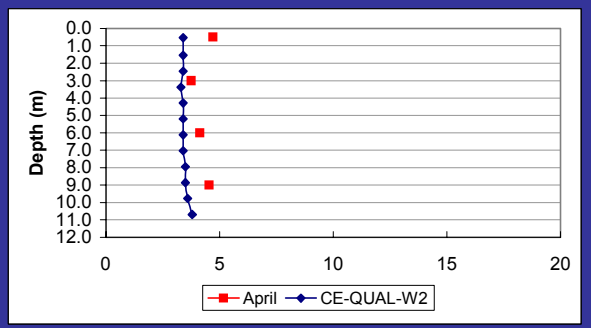
15
20
March
CE-QUAL-W2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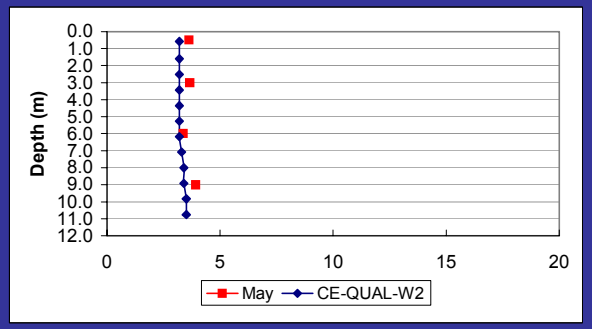
15
20
April
CE-QUAL-W2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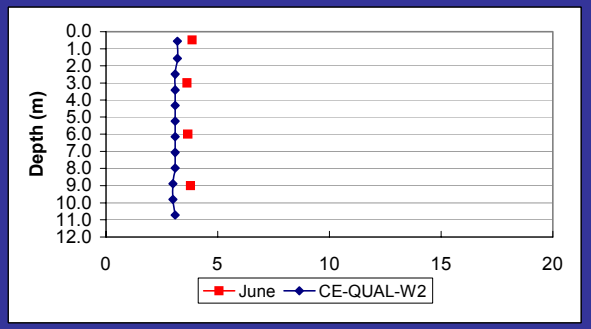
15
20
May
CE-QUAL-W2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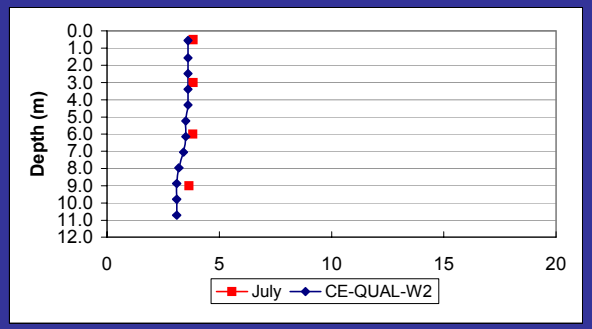
20
June
CE-QUAL-W2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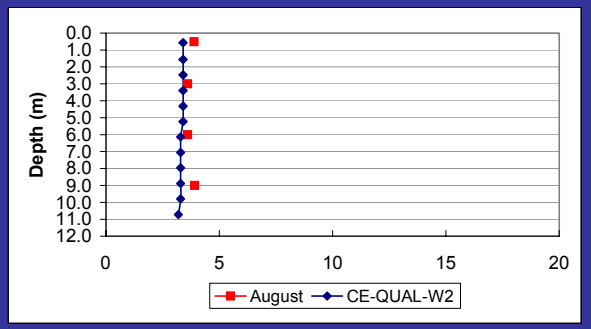
20
July
CE-QUAL-W2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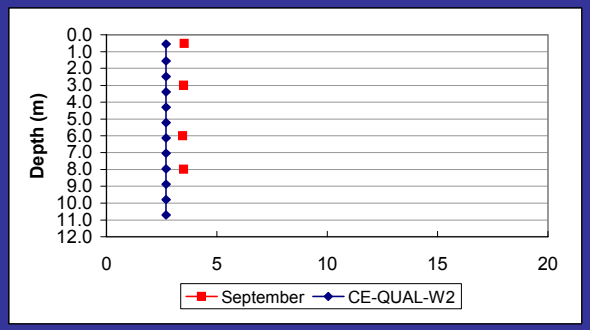
20
August
CE-QUAL-W2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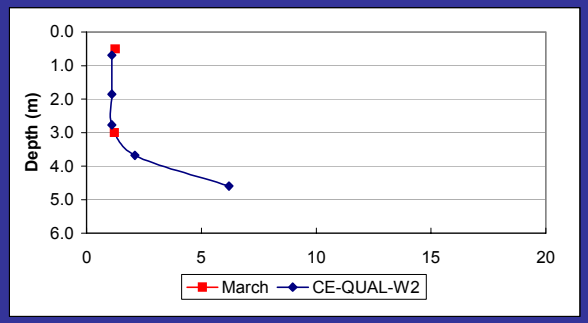
20
September
CE-QUAL-W2

Station 3


Depth (m)
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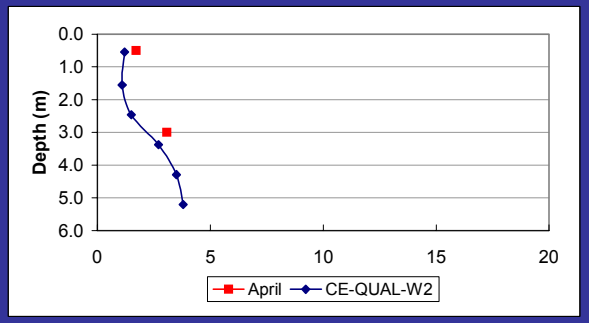
March
CE-QUAL-W2


Depth (m)
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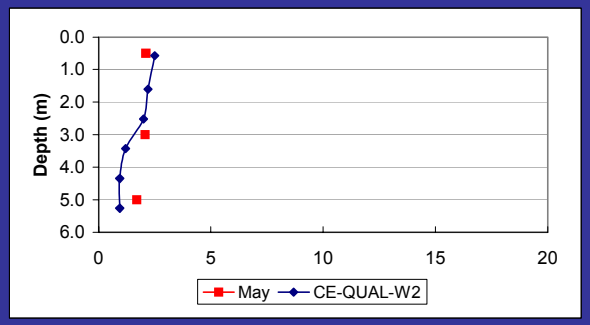
April
CE-QUAL-W2


Depth (m)
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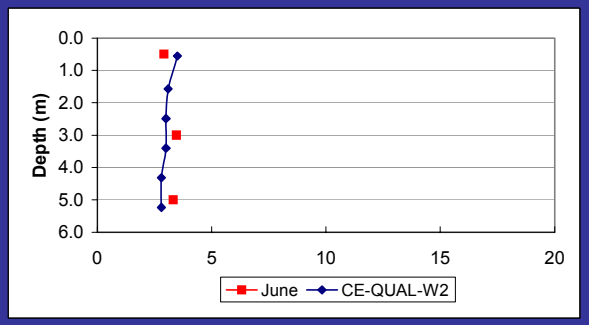
May
CE-QUAL-W2


Depth (m)
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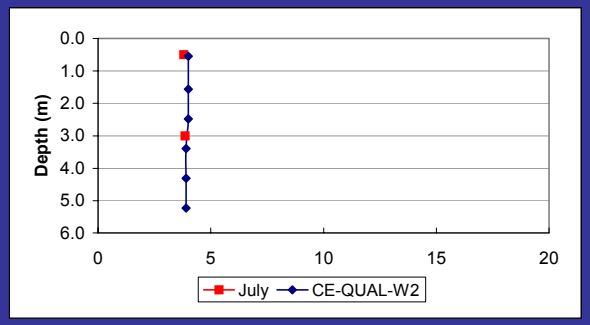
June
CE-QUAL-W2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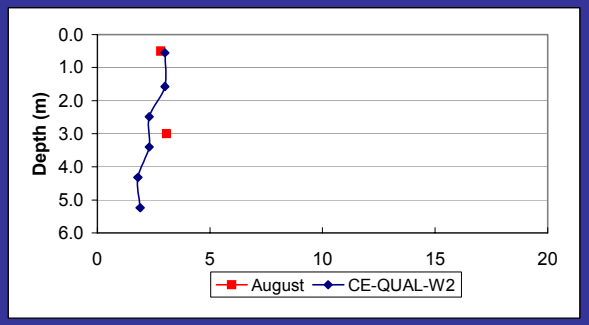
July
CE-QUAL-W2


Depth (m)
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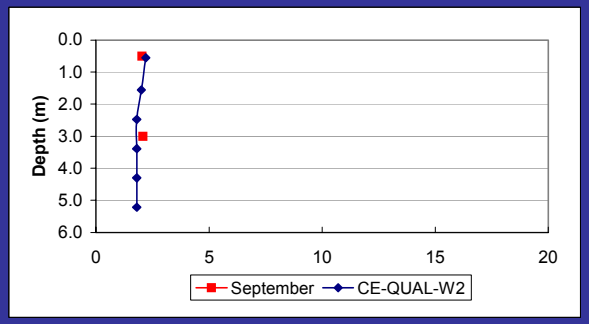
15
20
August
CE-QUAL-W2


Depth (m)
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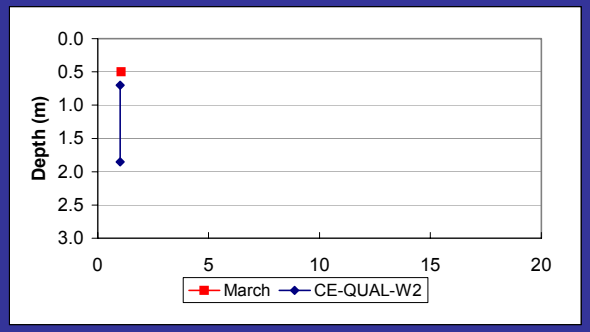
10
15
20
September
CE-QUAL-W2

Station 4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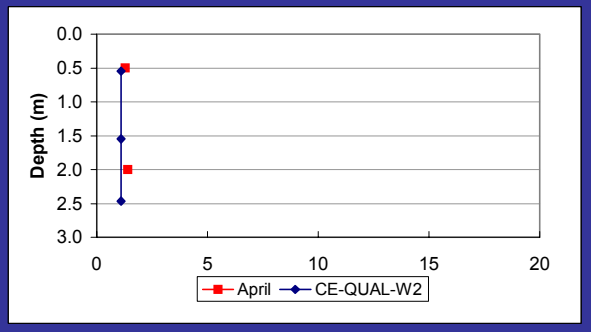
10
15
20
March
CE-QUAL-W2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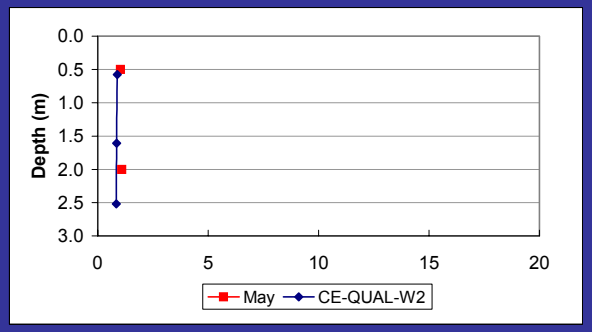
April
CE-QUAL-W2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2.5
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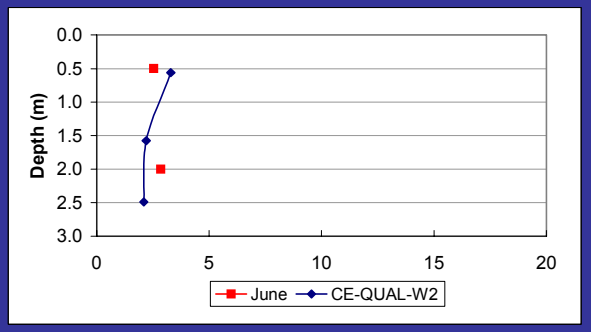
10
15
20
May
CE-QUAL-W2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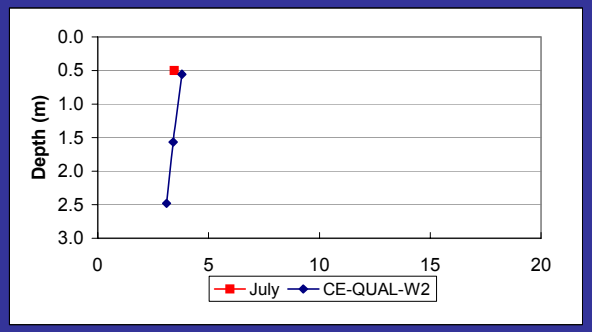
15
20
June
CE-QUAL-W2


Depth (m)
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2.5
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15
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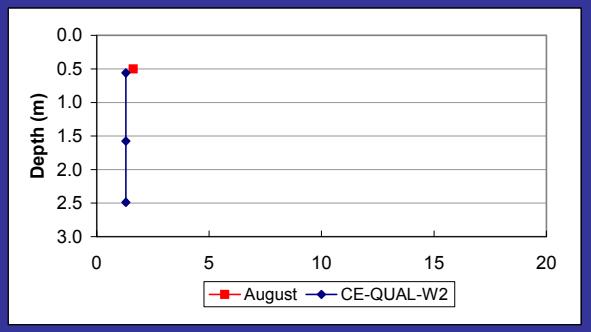
July
CE-QUAL-W2


Depth (m)
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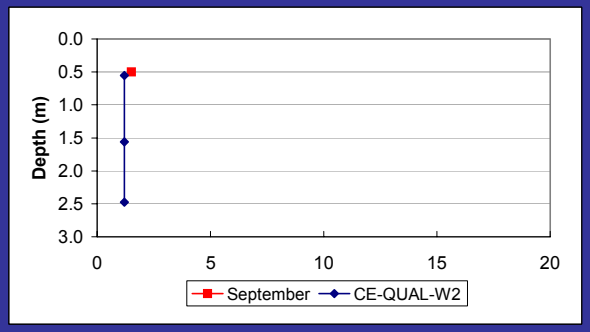
August
CE-QUAL-W2


Depth (m)
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2.5
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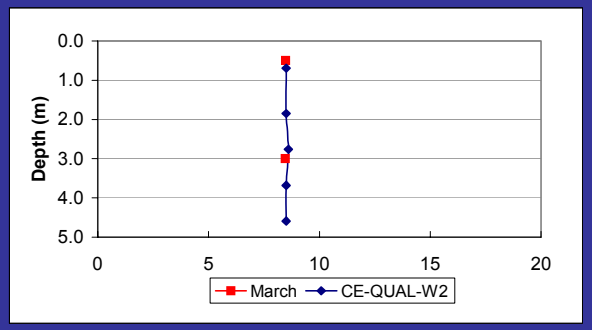
10
15
20
September
CE-QUAL-W2

Station 5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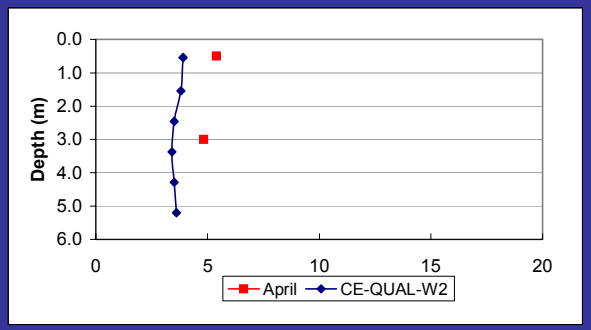
15
20
March
CE-QUAL-W2


Depth (m)
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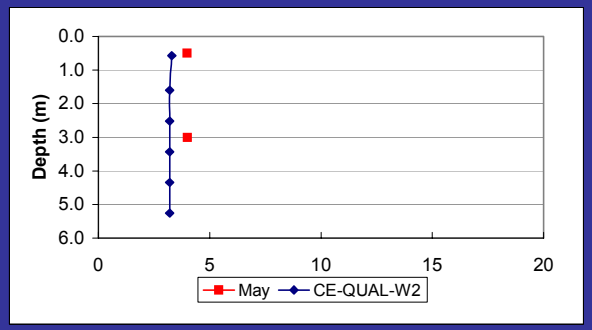
10
15
20
April
CE-QUAL-W2


Depth (m)
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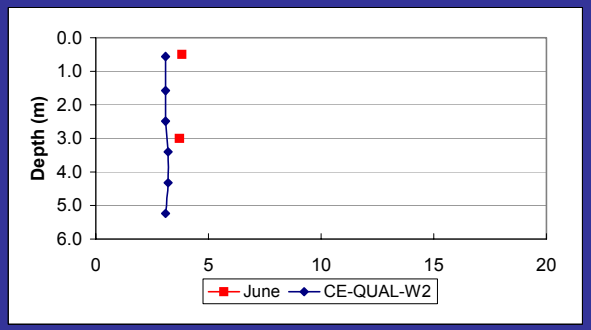
15
20
May
CE-QUAL-W2


Depth (m)
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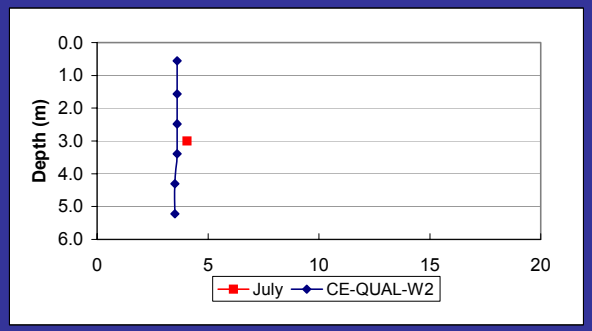
10
15
20
June
CE-QUAL-W2


Depth (m)
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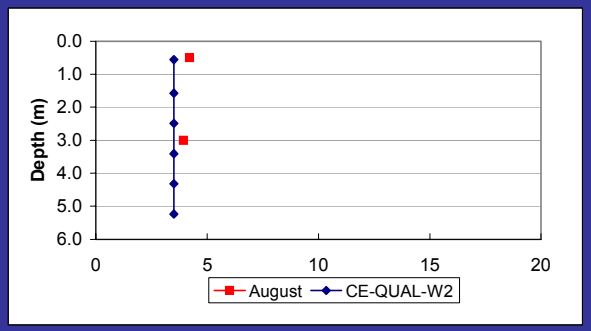
10
15
20
July
CE-QUAL-W2


Depth (m)
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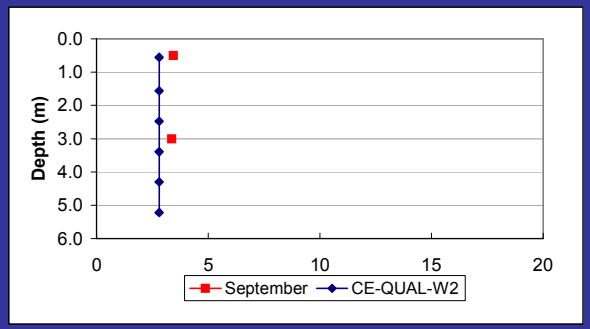
20
August
CE-QUAL-W2


Depth (m)
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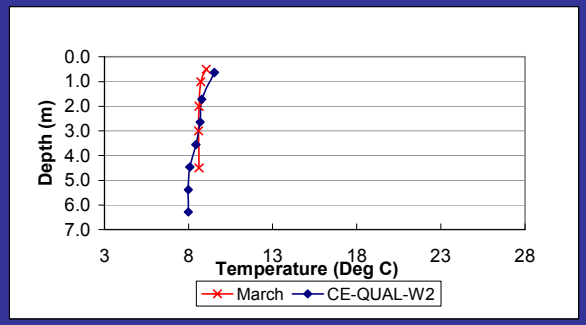
10
15
20
September
CE-QUAL-W2

Station 6


Depth (m)
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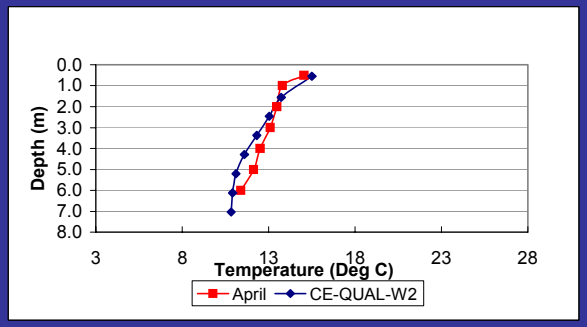
3
8
13
18
23
28
Temperature (Deg C)
March
CE-QUAL-W2


Depth (m)
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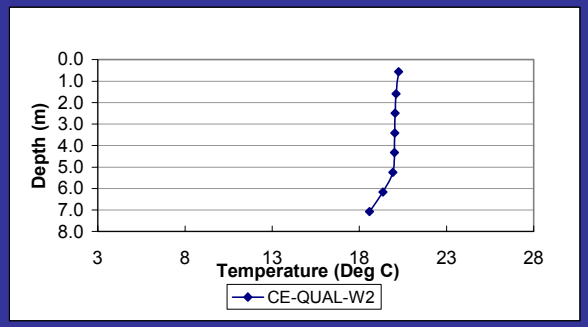
8.0
3
8
13
18
23
28
Temperature (Deg C)
April
CE-QUAL-W2


Depth (m)
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1.0
2.0
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5.0
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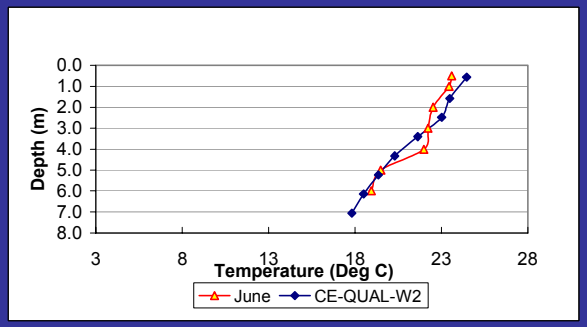
8.0
3
8
13
18
23
28
Temperature (Deg C)
CE-QUAL-W2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2.0
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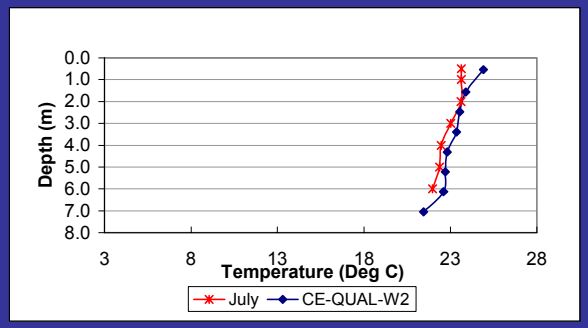
18
23
28
Temperature (Deg C)
June
CE-QUAL-W2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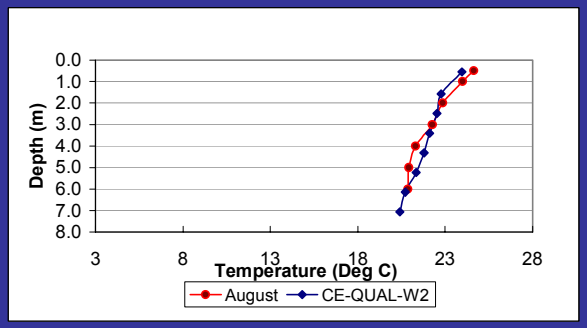
23
28
Temperature (Deg C)
July
CE-QUAL-W2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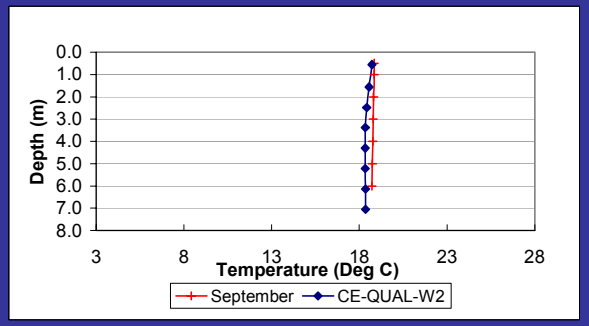
23
28
Temperature (Deg C)
August
CE-QUAL-W2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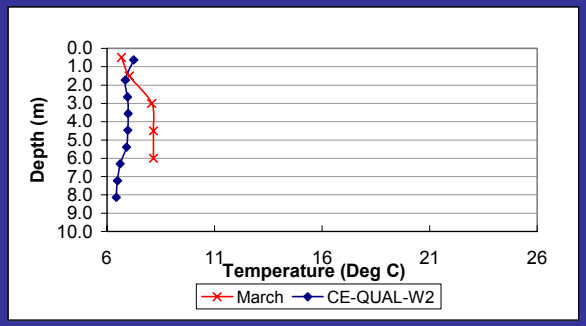
Temperature (Deg C)
September
CE-QUAL-W2

Station 1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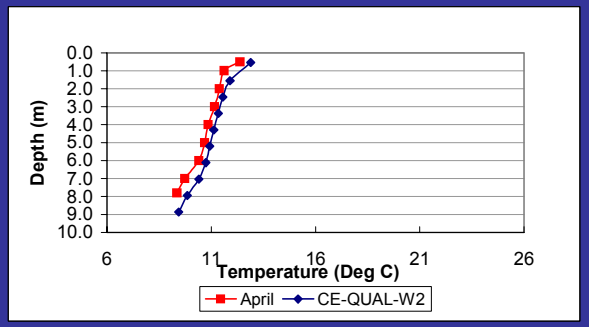
16
21
26
Temperature (Deg C)
March
CE-QUAL-W2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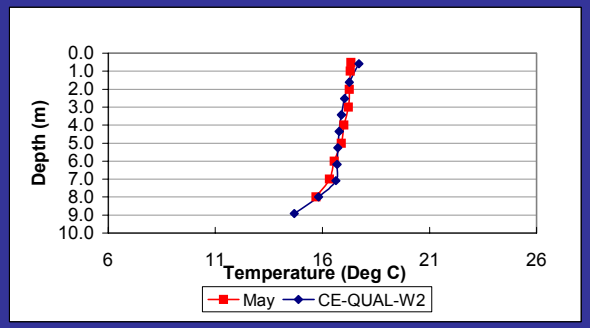
21
26
Temperature (Deg C)
April
CE-QUAL-W2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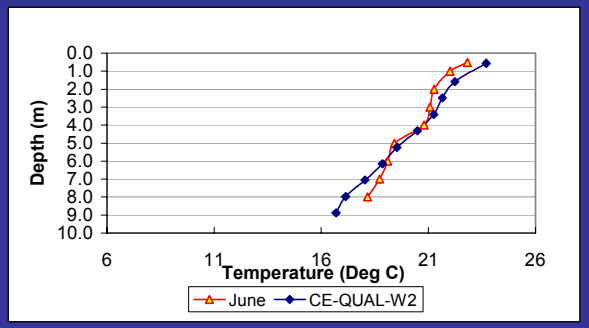
16
21
26
Temperature (Deg C)
May
CE-QUAL-W2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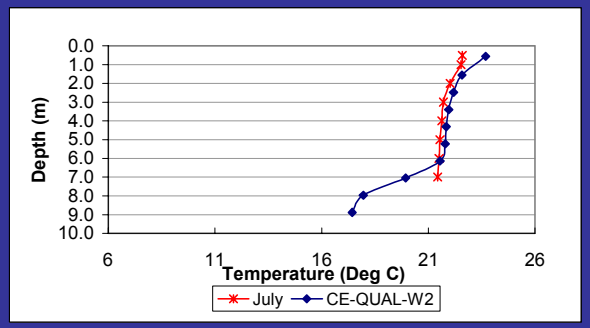
11
16
21
26
Temperature (Deg C)
June
CE-QUAL-W2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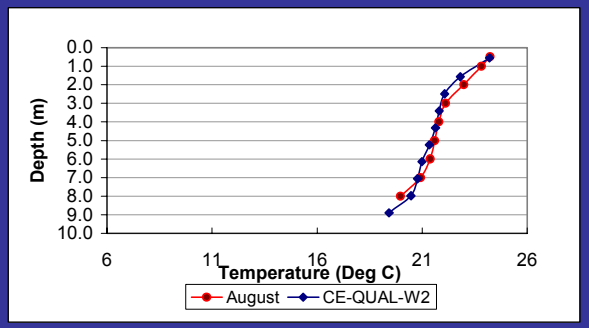
16
21
26
Temperature (Deg C)
July
CE-QUAL-W2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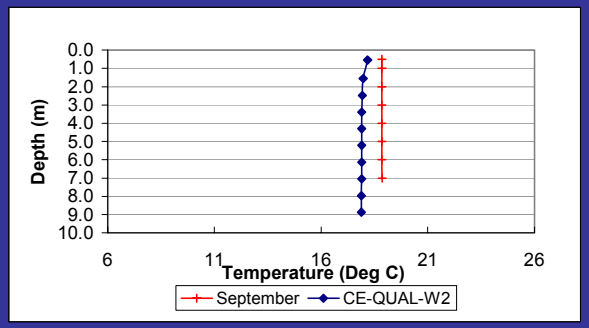
11
16
21
26
Temperature (Deg C)
August
CE-QUAL-W2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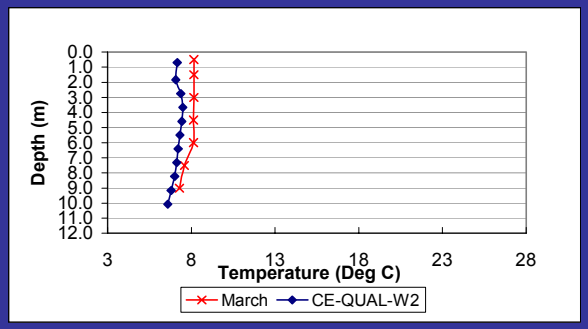
6
11
16
21
26
Temperature (Deg C)
September
CE-QUAL-W2

Station 2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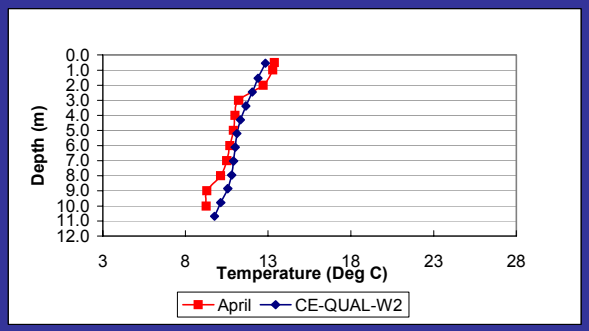
Temperature (Deg C)
March
CE-QUAL-W2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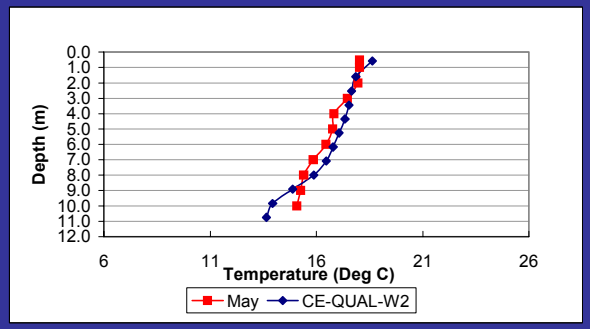
Temperature (Deg C)
April
CE-QUAL-W2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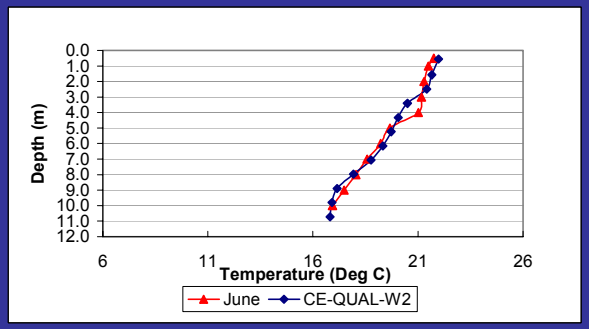
16
21
26
Temperature (Deg C)
May
CE-QUAL-W2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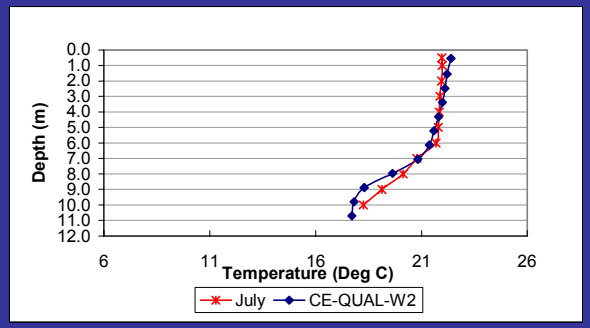
11
16
21
26
Temperature (Deg C)
June
CE-QUAL-W2


Depth (m)
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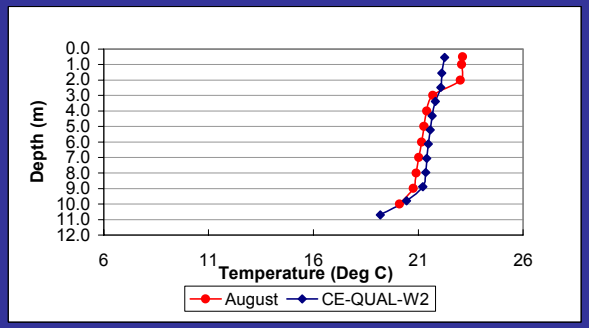
11
16
21
26
Temperature (Deg C)
July
CE-QUAL-W2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12.0
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11
16
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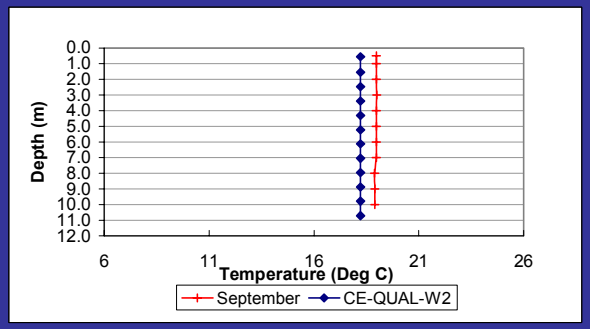
26
Temperature (Deg C)
August
CE-QUAL-W2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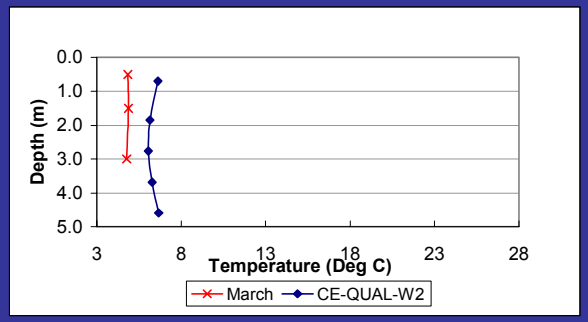
11
16
21
26
Temperature (Deg C)
September
CE-QUAL-W2

Station 3


Depth (m)
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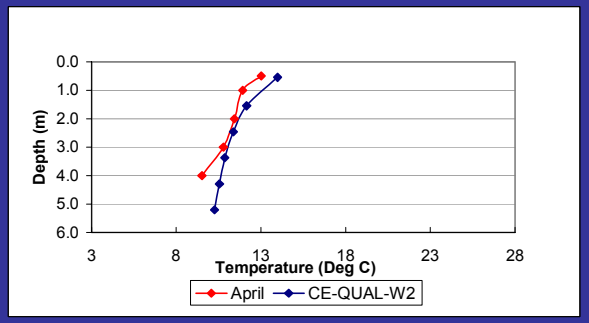
5.0
3
8
13
18
23
28
Temperature (Deg C)
March
CE-QUAL-W2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8
13
18
23
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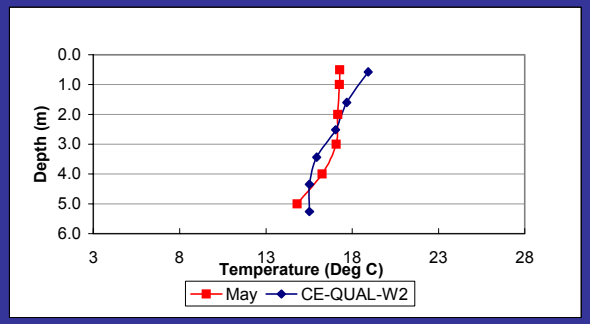
Temperature (Deg C)
April
CE-QUAL-W2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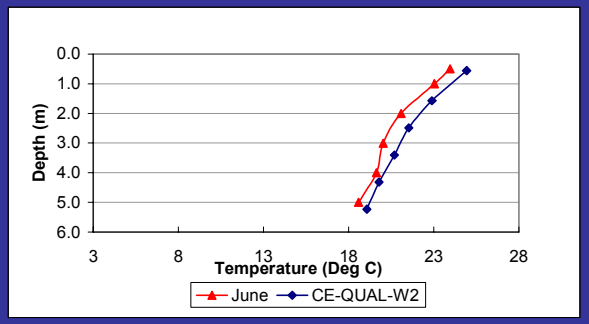
13
18
23
28
Temperature (Deg C)
May
CE-QUAL-W2


Depth (m)
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8
13
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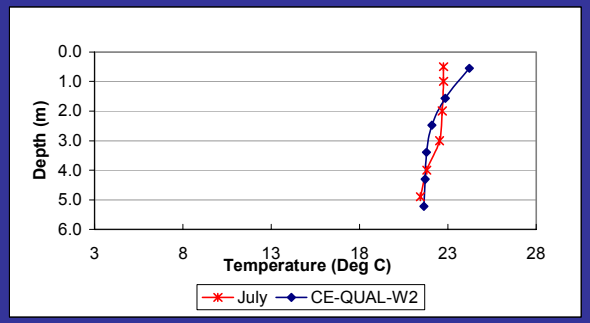
23
28
Temperature (Deg C)
June
CE-QUAL-W2


Depth (m)
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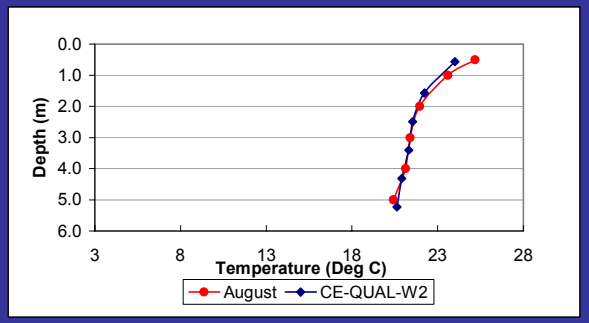
13
18
23
28
Temperature (Deg C)
July
CE-QUAL-W2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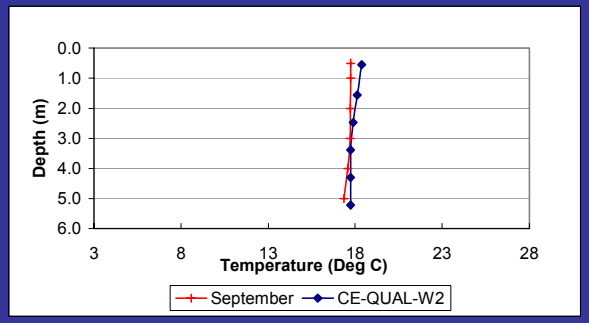
23
28
Temperature (Deg C)
August
CE-QUAL-W2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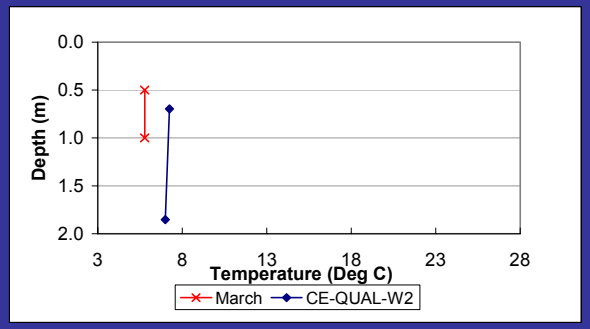
23
28
Temperature (Deg C)
September
CE-QUAL-W2

Station 4


Depth (m)
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1.5
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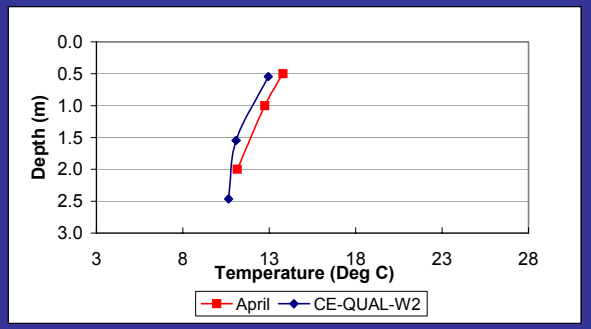
3
8
13
18
23
28
Temperature (Deg C)
March
CE-QUAL-W2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3.0
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8
13
18
23
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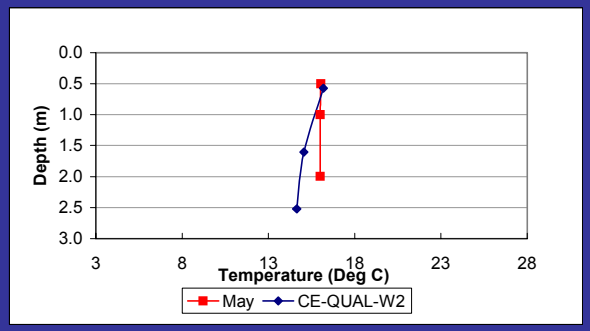
Temperature (Deg C)
April
CE-QUAL-W2


Depth (m)
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2.5
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18
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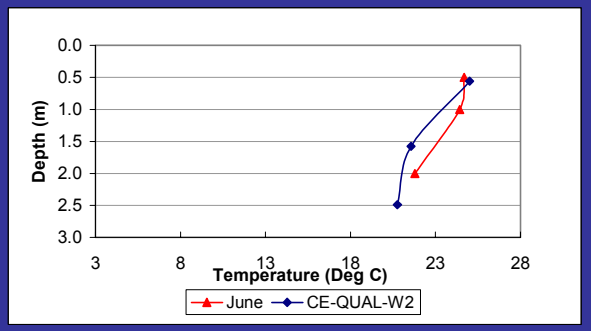
Temperature (Deg C)
May
CE-QUAL-W2


Depth (m)
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2.5
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3
8
13
18
23
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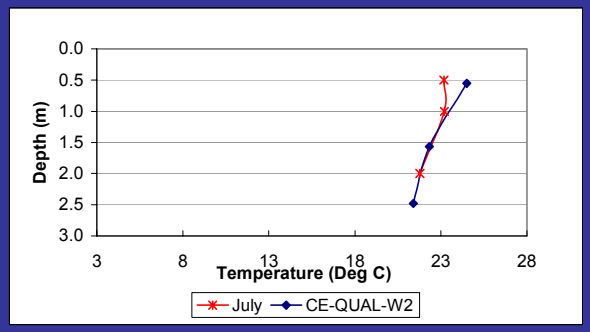
Temperature (Deg C)
June
CE-QUAL-W2


Depth (m)
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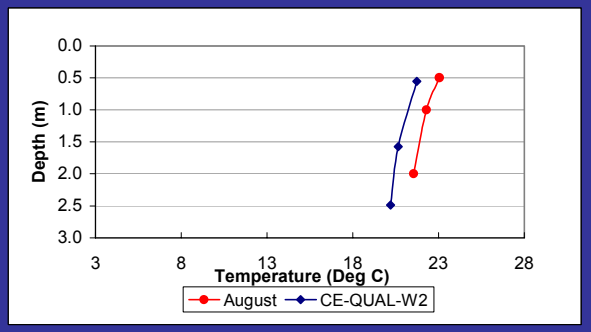
1.0
1.5
2.0
2.5
3.0
3
8
13
18
23
28
Temperature (Deg C)
July
CE-QUAL-W2


Depth (m)
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2.5
3.0
3
8
13
18
23
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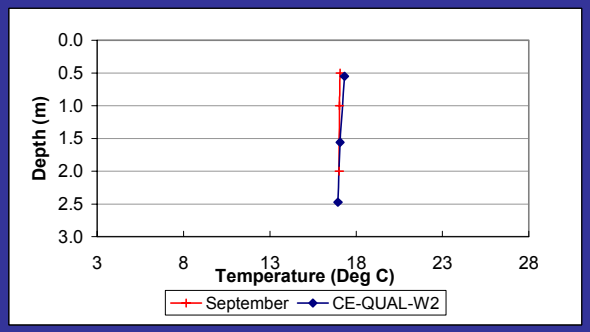
Temperature (Deg C)
August
CE-QUAL-W2


Depth (m)
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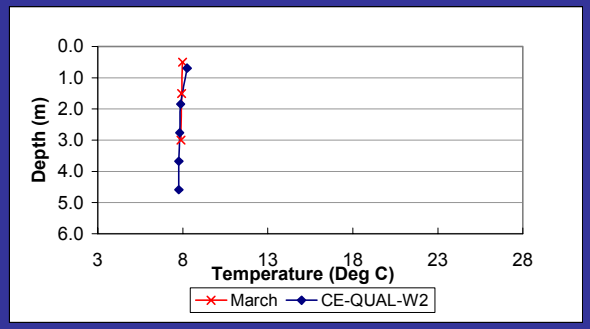
8
13
18
23
28
Temperature (Deg C)
September
CE-QUAL-W2

Station 5


Depth (m)
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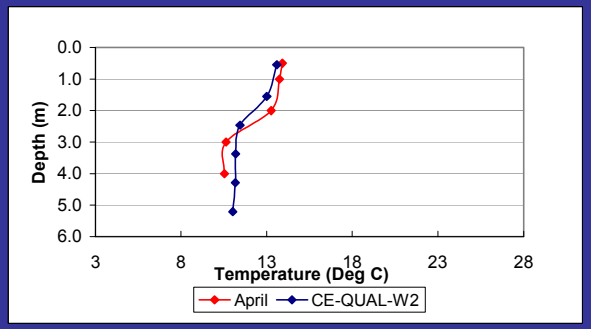
18
23
28
Temperature (Deg C)
March
CE-QUAL-W2


Depth (m)
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8
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18
23
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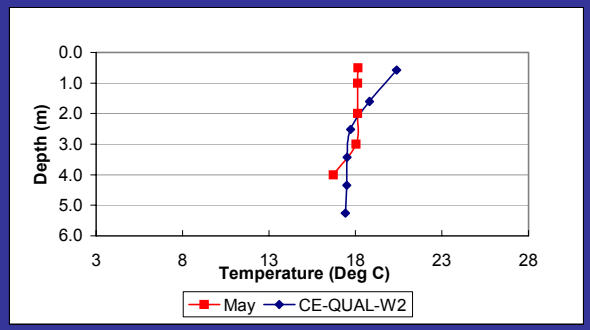
Temperature (Deg C)
April
CE-QUAL-W2


Depth (m)
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23
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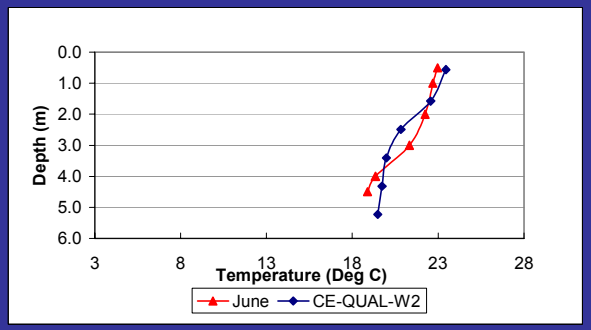
Temperature (Deg C)
May
CE-QUAL-W2


Depth (m)
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5.0
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8
13
18
23
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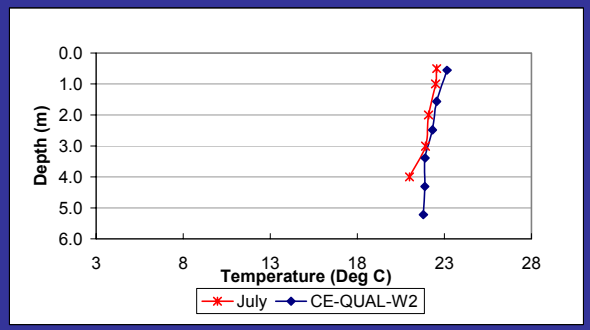
Temperature (Deg C)
June
CE-QUAL-W2


Depth (m)
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18
23
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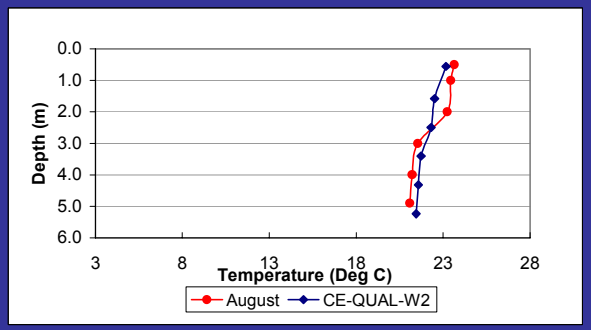
Temperature (Deg C)
July
CE-QUAL-W2


Depth (m)
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1.0
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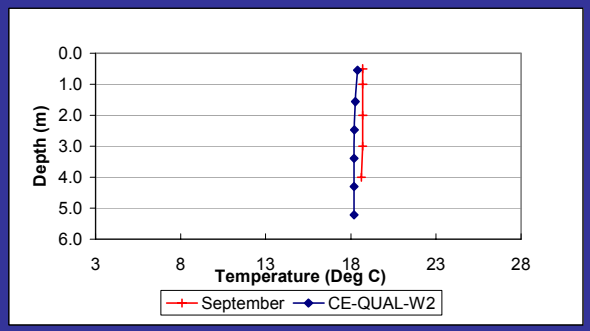
3
8
13
18
23
28
Temperature (Deg C)
August
CE-QUAL-W2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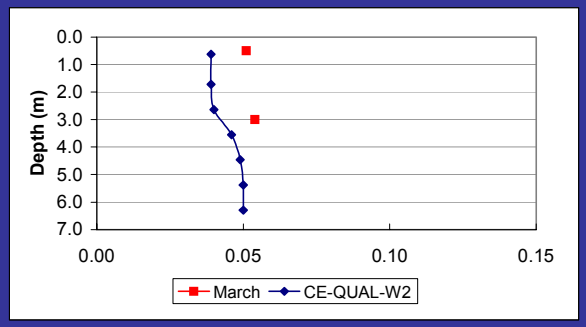
8
13
18
23
28
Temperature (Deg C)
September
CE-QUAL-W2

Station 6

Model Goals

- Develop an accurate water balance
- Simulate hydrodynamics of Moses Lake
- Calibrate 2000-01 phosphorus loads to Moses Lake with observed in-lake phosphorus concentrations
- Model in-lake phosphorus concentrations for a critical phosphorus loading year and use model as a management tool for phosphorus reduction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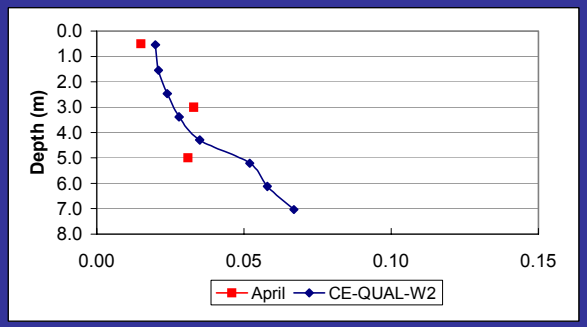
0.15
March
CE-QUAL-W2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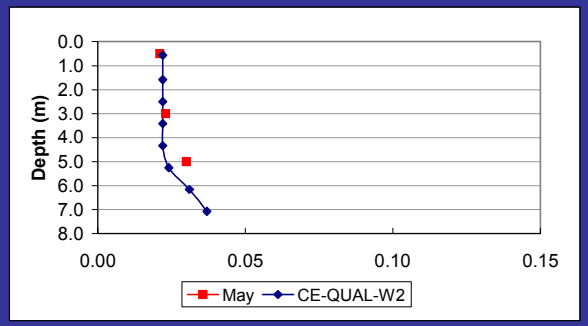
0.15
April
CE-QUAL-W2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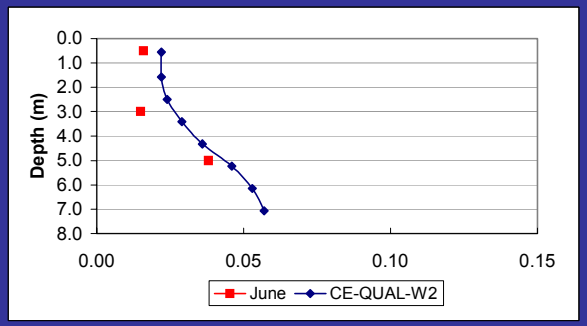
0.15
May
CE-QUAL-W2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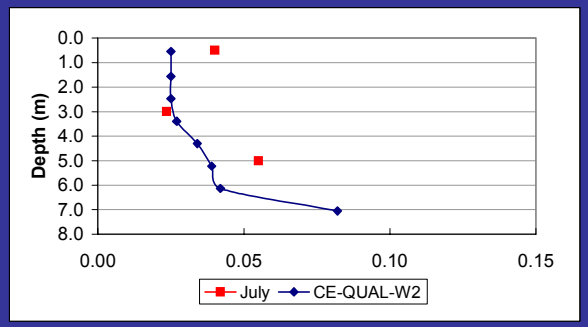
June
CE-QUAL-W2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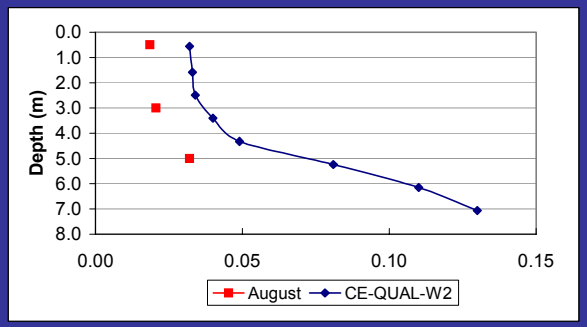
July
CE-QUAL-W2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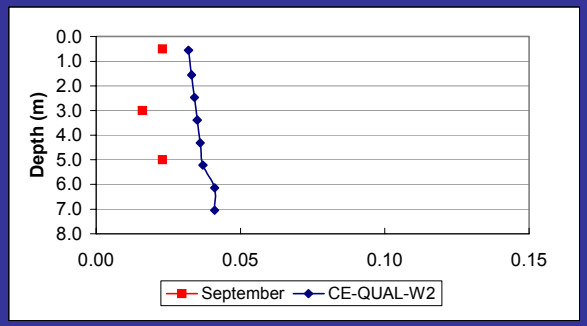
0.15
August
CE-QUAL-W2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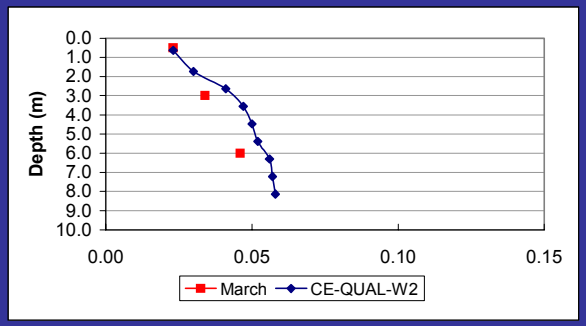
0.10
0.15
September
CE-QUAL-W2

Station 1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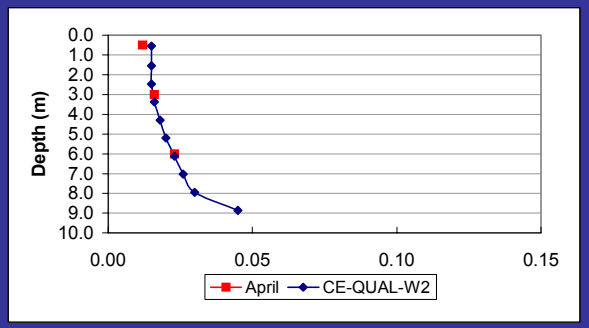
0.10
0.15
March
CE-QUAL-W2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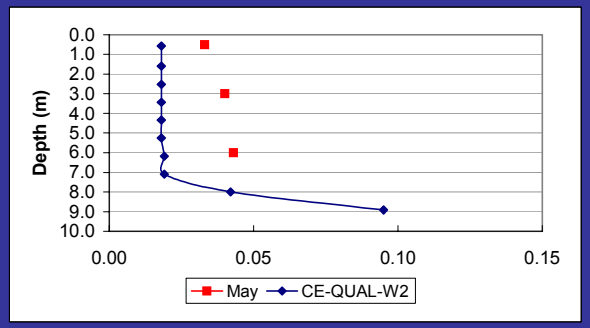
0.15
April
CE-QUAL-W2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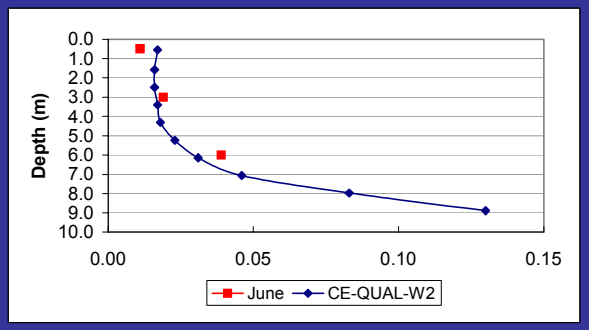
0.05
0.10
0.15
May
CE-QUAL-W2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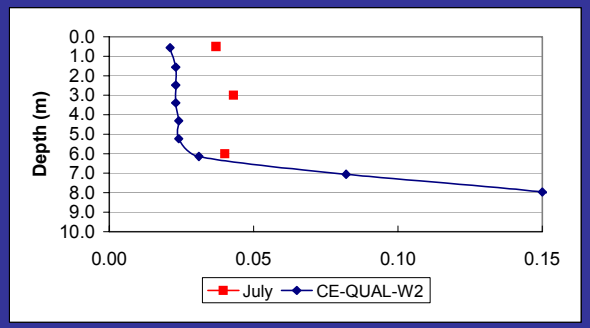
0.15
June
CE-QUAL-W2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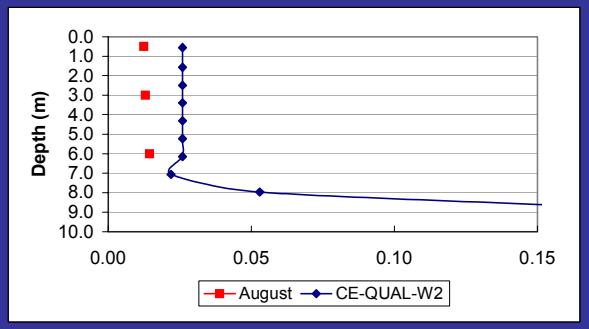
July
CE-QUAL-W2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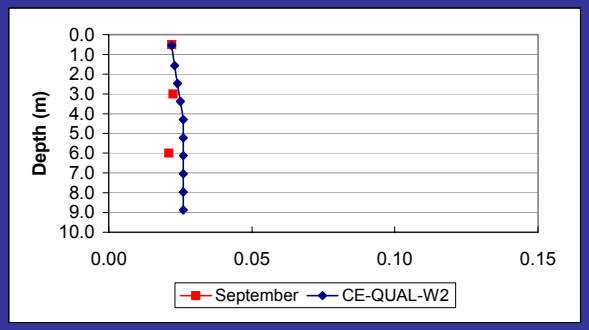
August
CE-QUAL-W2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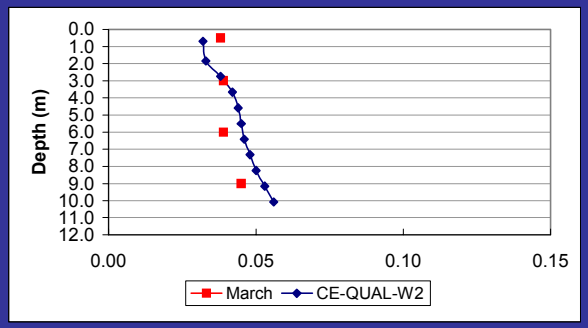
0.15
September
CE-QUAL-W2

Station 2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0.00
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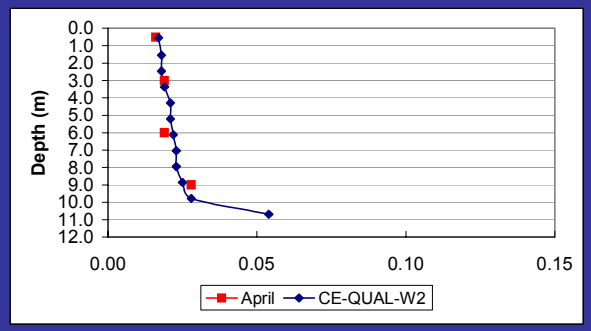
0.10
0.15
March
CE-QUAL-W2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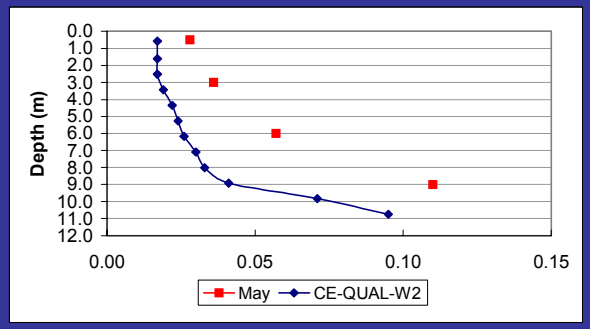
0.15
April
CE-QUAL-W2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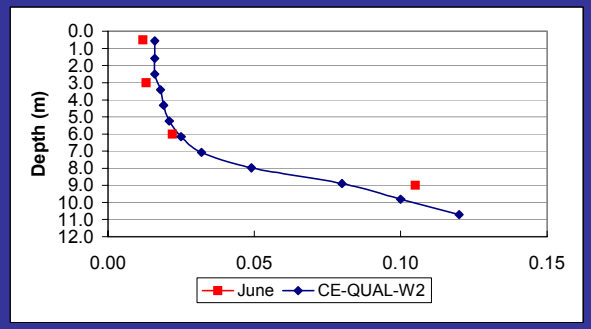
0.15
May
CE-QUAL-W2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12.0
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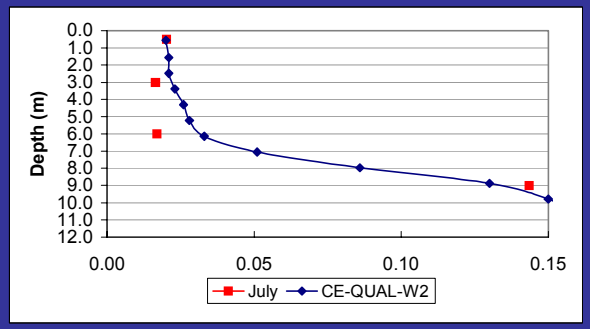
0.15
June
CE-QUAL-W2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12.0
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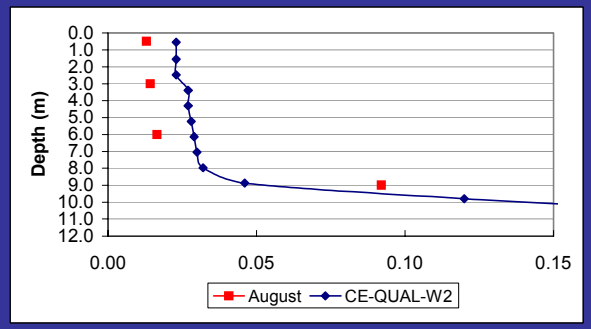
0.05
0.10
0.15
July
CE-QUAL-W2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12.0
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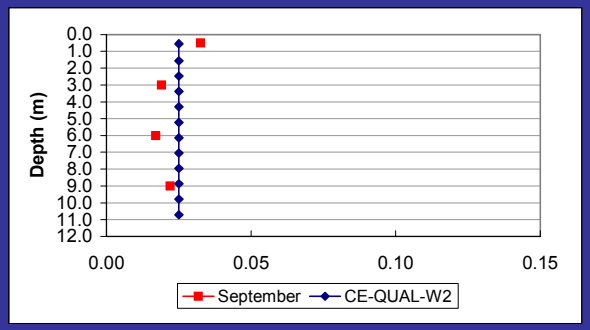
0.10
0.15
August
CE-QUAL-W2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12.0
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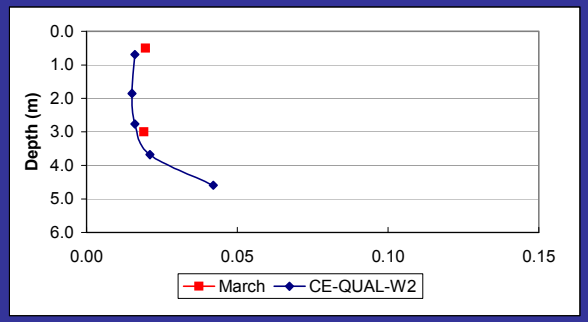
0.10
0.15
September
CE-QUAL-W2

Station 3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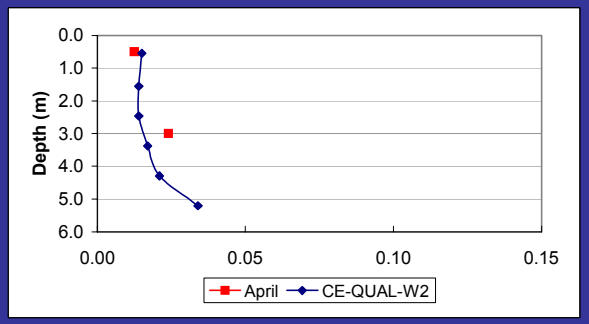
0.05
0.10
0.15
March
CE-QUAL-W2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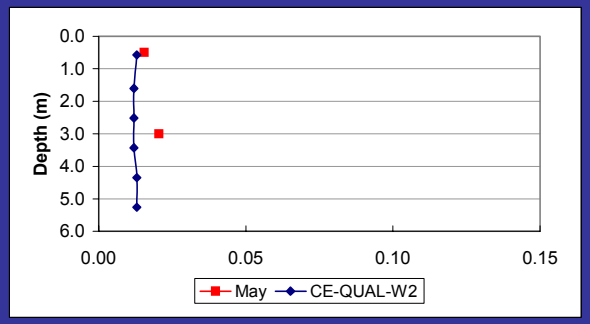
April
CE-QUAL-W2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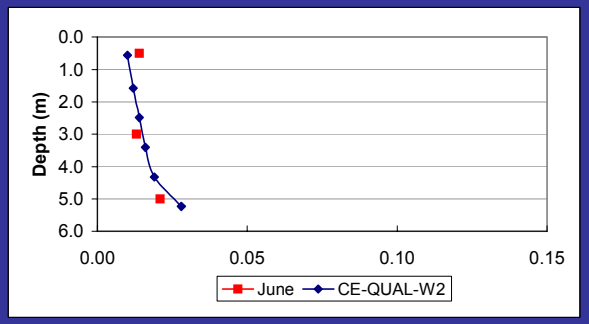
0.15
May
CE-QUAL-W2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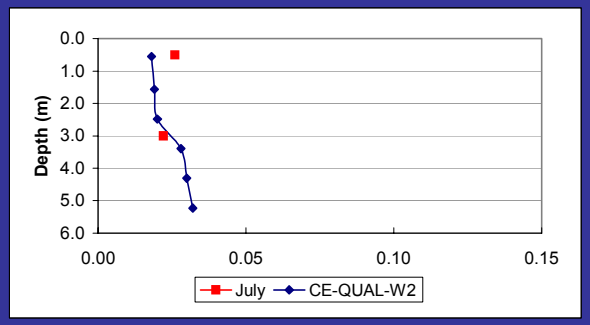
0.15
June
CE-QUAL-W2


Depth (m)
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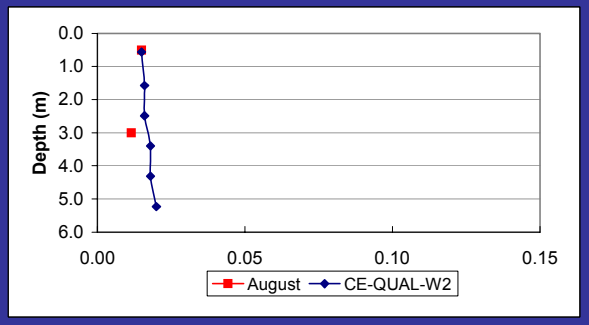
0.10
0.15
July
CE-QUAL-W2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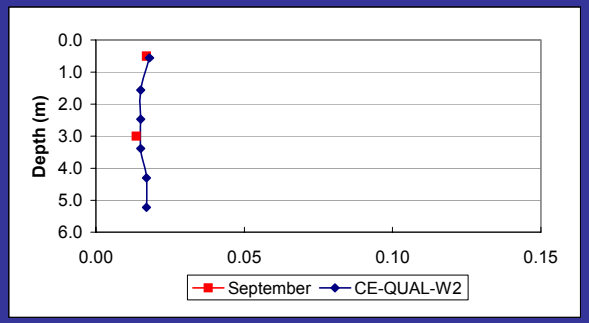
August
CE-QUAL-W2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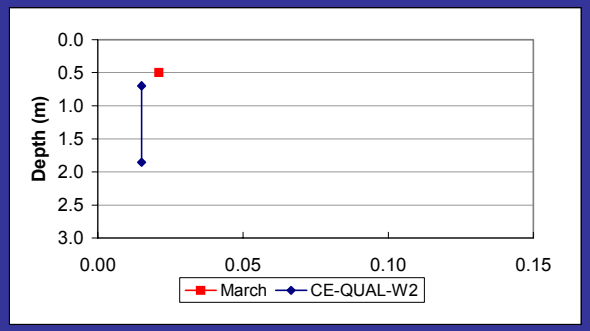
0.05
0.10
0.15
September
CE-QUAL-W2

Station 4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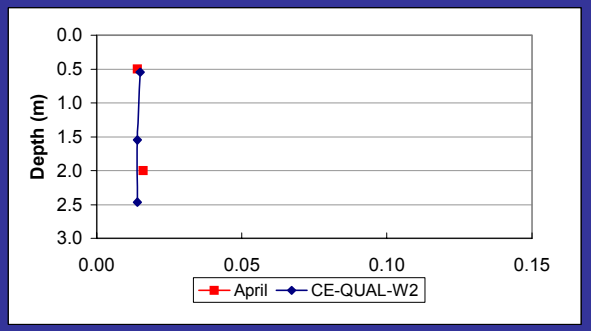
2.0
2.5
3.0
0.00
0.05
0.10
0.15
March
CE-QUAL-W2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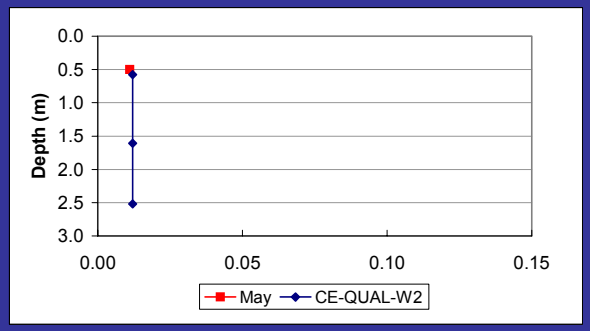
0.10
0.15
April
CE-QUAL-W2


Depth (m)
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2.5
3.0
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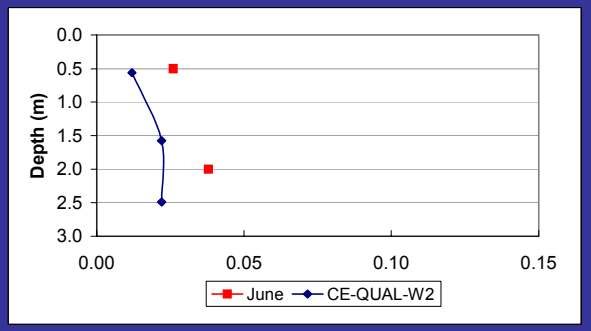
0.10
0.15
May
CE-QUAL-W2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2.5
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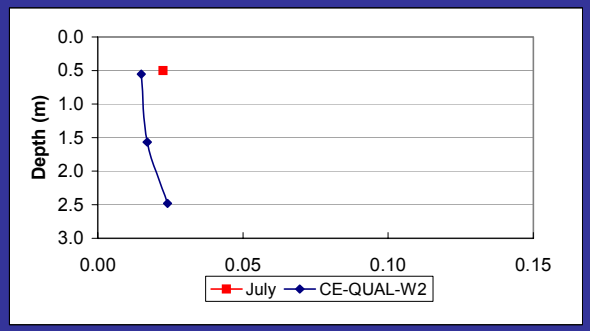
0.15
June
CE-QUAL-W2


Depth (m)
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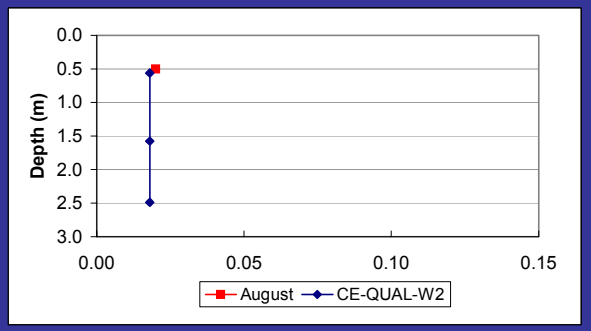
1.0
1.5
2.0
2.5
3.0
0.00
0.05
0.10
0.15
July
CE-QUAL-W2


Depth (m)
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2.5
3.0
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0.05
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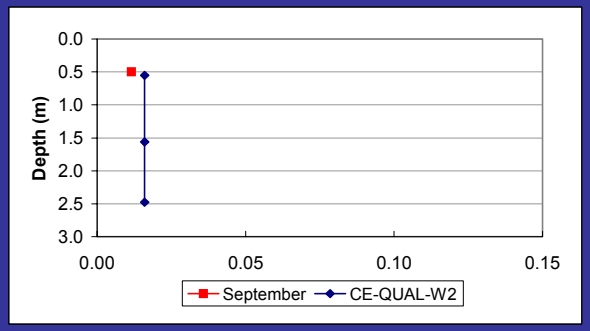
August
CE-QUAL-W2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3.0
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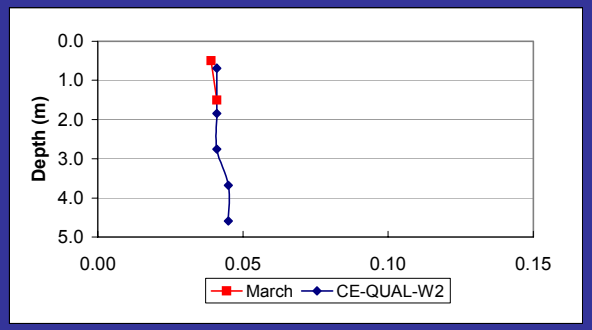
0.05
0.10
0.15
September
CE-QUAL-W2

Station 5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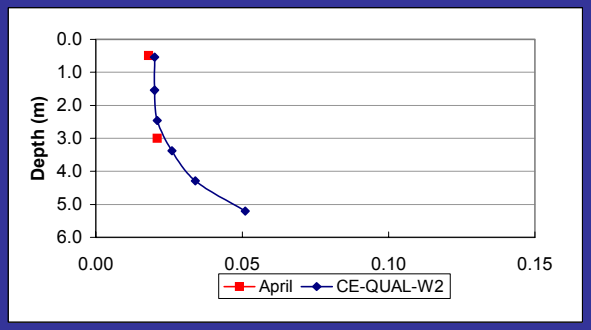
0.10
0.15
March
CE-QUAL-W2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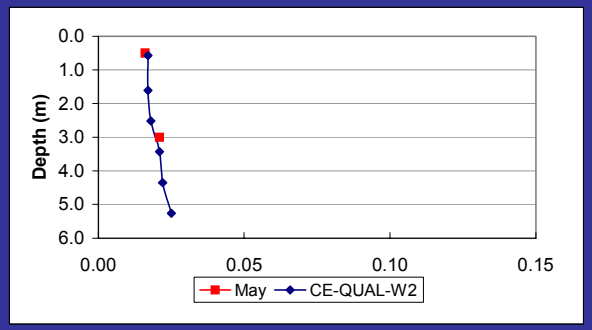
0.05
0.10
0.15
April
CE-QUAL-W2


Depth (m)
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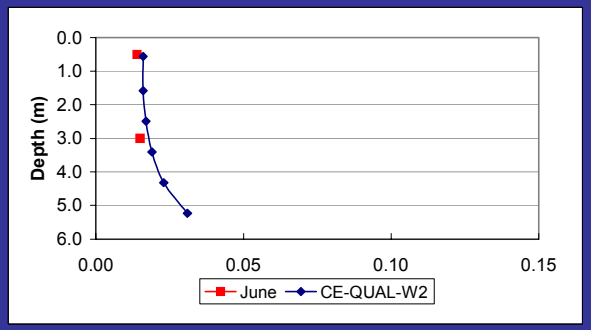
2.0
3.0
4.0
5.0
6.0
0.00
0.05
0.10
0.15
May
CE-QUAL-W2


Depth (m)
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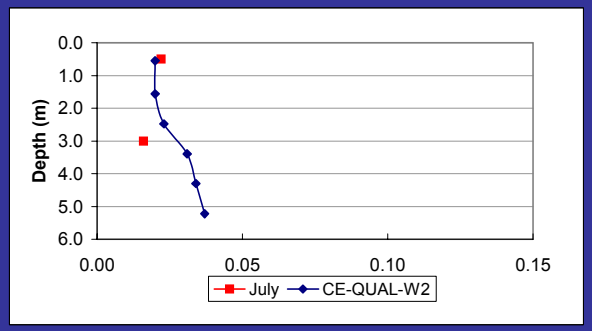
1.0
2.0
3.0
4.0
5.0
6.0
0.00
0.05
0.10
0.15
June
CE-QUAL-W2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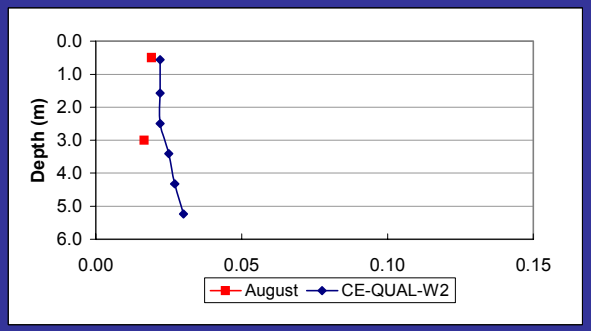
2.0
3.0
4.0
5.0
6.0
0.00
0.05
0.10
0.15
July
CE-QUAL-W2


Depth (m)
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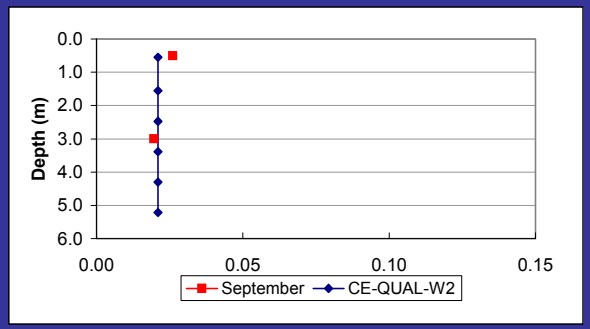
2.0
3.0
4.0
5.0
6.0
0.00
0.05
0.10
0.15
August
CE-QUAL-W2


Depth (m)
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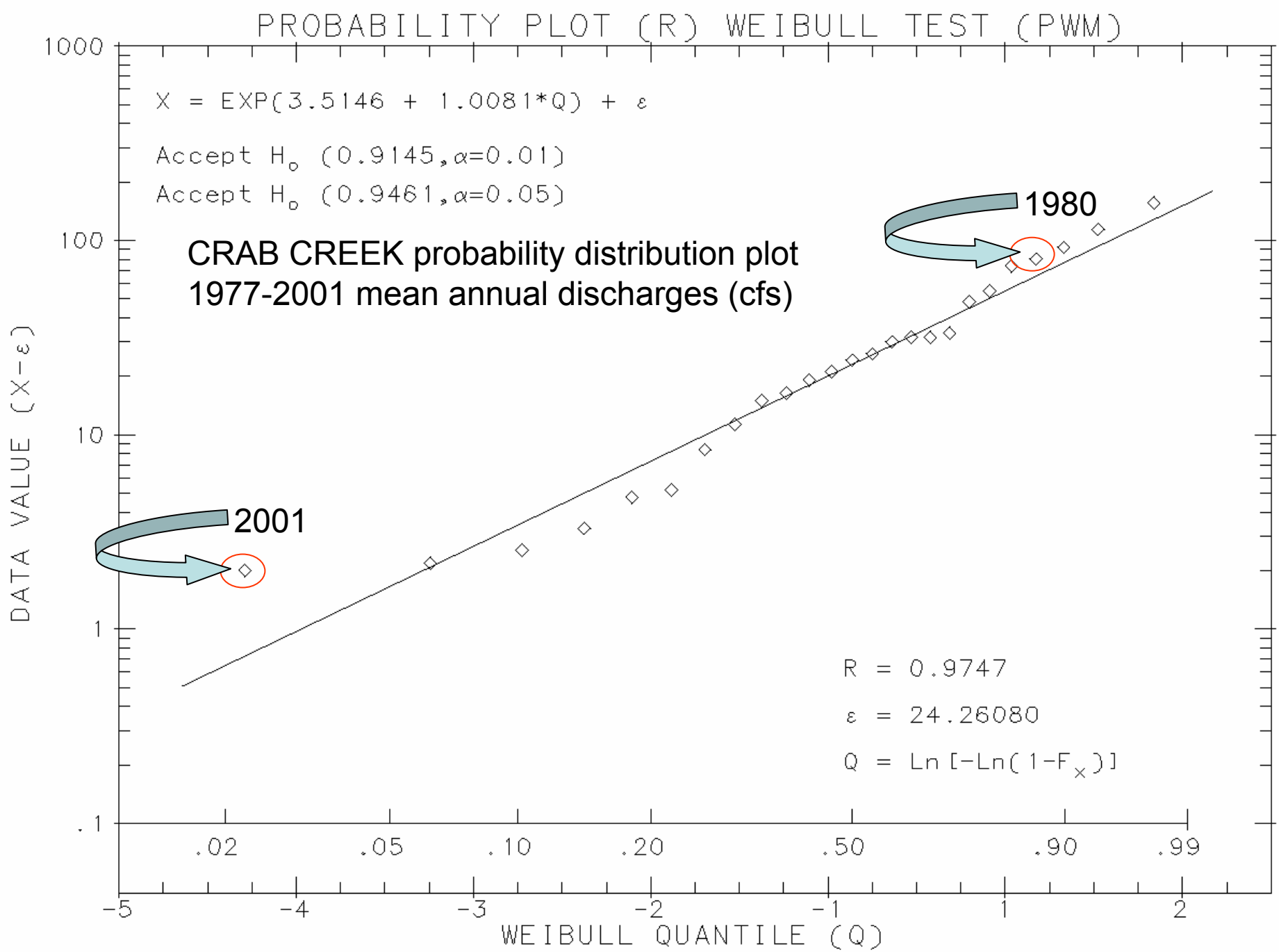
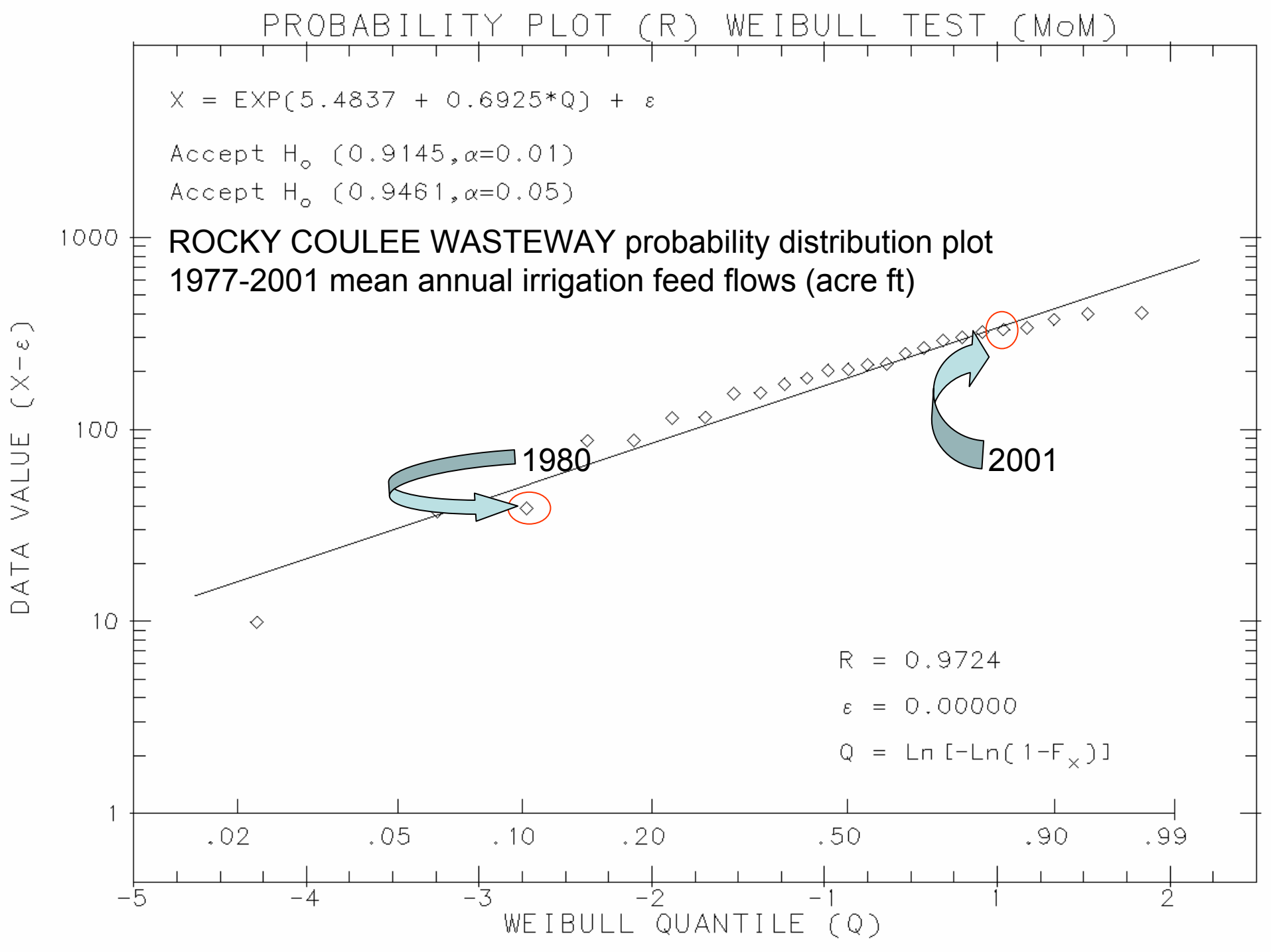
1.0
2.0
3.0
4.0
5.0
6.0
0.00
0.05
0.10
0.15
September
CE-QUAL-W2

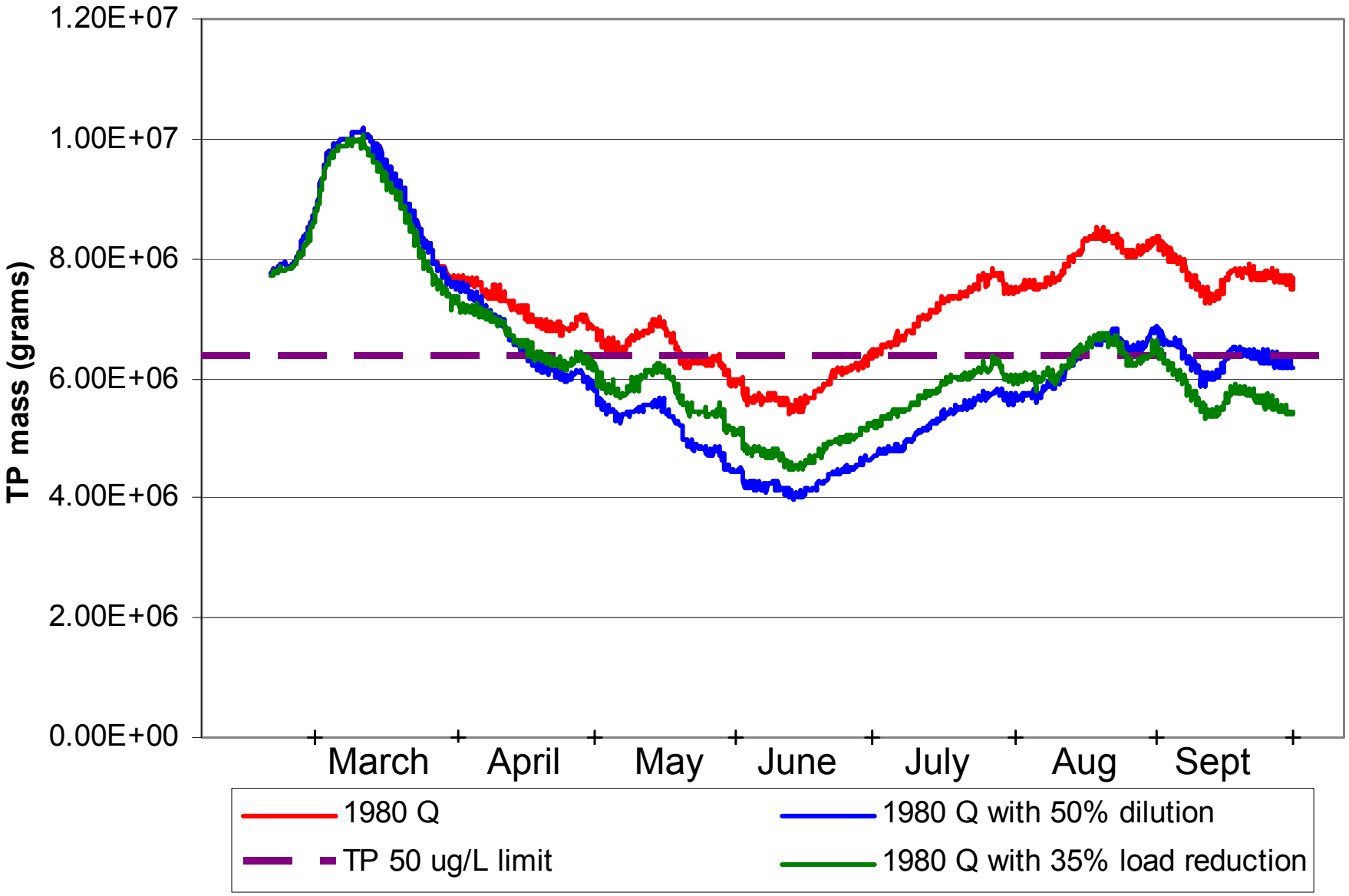
Station 6

Model Goals

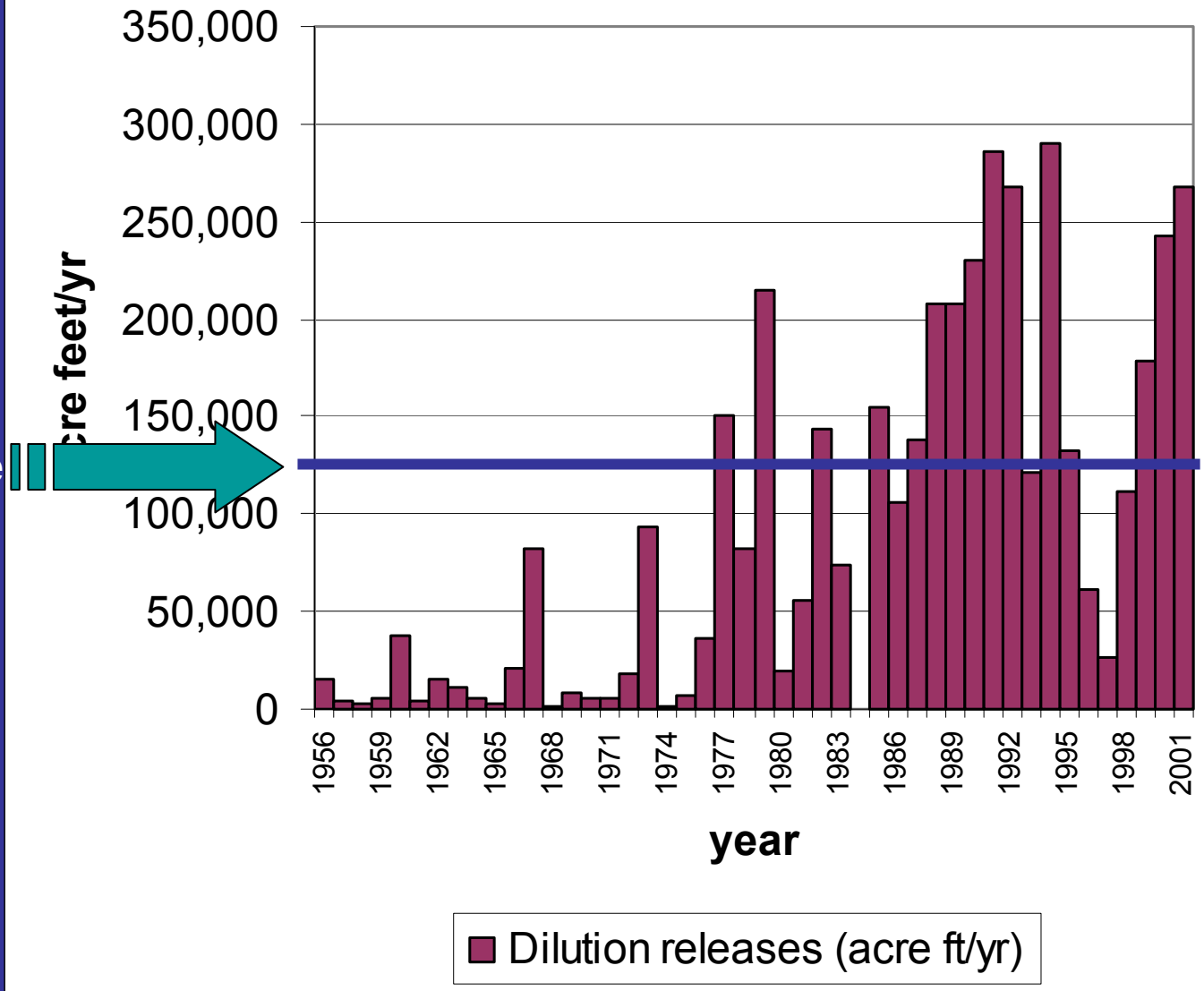
- Develop an accurate water balance
- Simulate hydrodynamics of Moses Lake
- Calibrate 2000-01 phosphorus loads to Moses Lake with observed in-lake phosphorus concentrations
- Model in-lake phosphorus concentrations for a critical phosphorus loading year and use model as a management tool for phosphorus reduction


PROBABILITY PLOT (R) WEIBULL TEST (PWM)
X = EXP(3.5146 + 1.0081*Q) + ε
Accept H₀ (0.9145, α=0.01)
Accept H₀ (0.9461, α=0.05)
CRAB CREEK probability distribution plot
1977-2001 mean annual discharges (cfs)
1980
2001
R = 0.9747
ε = 24.26080
Q = Ln[-Ln(1-F_X)]
DATA VALUE (X-ε)
1000
100
10
1
.1
.02
.05
.10
.20
.50
.90
.99
-5
-4
-3
-2
-1
1
2
WEIBULL QUANTILE (Q)

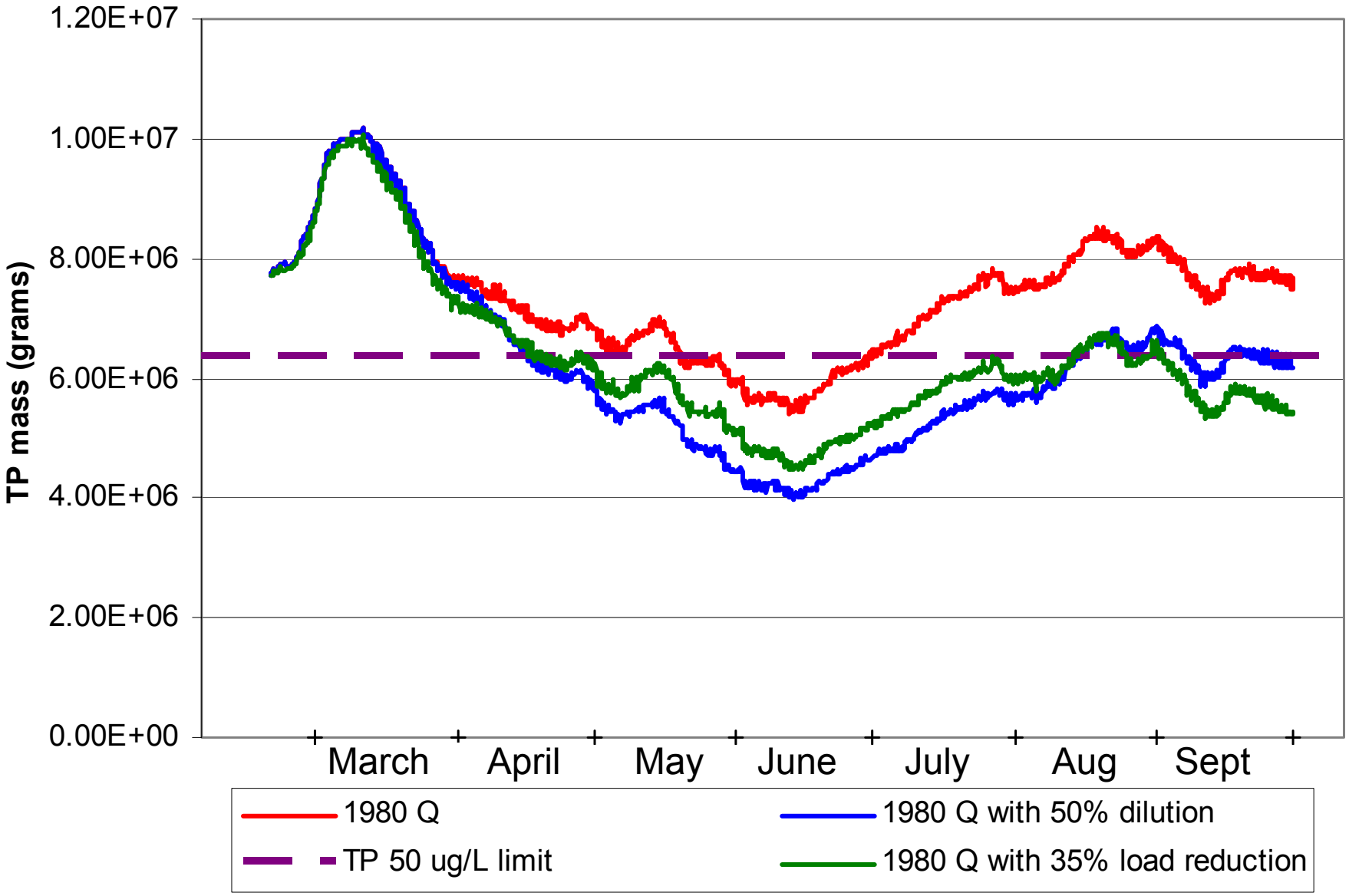

PROBABILITY PLOT (R) WEIBULL TEST (MoM)
X = EXP(5.4837 + 0.6925*Q) + ε
Accept H₀ (0.9145, α=0.01)
Accept H₀ (0.9461, α=0.05)
ROCKY COULEE WASTEWAY probability distribution plot
1977-2001 mean annual irrigation feed flows (acre ft)
1980
2001
R = 0.9724
ε = 0.00000
Q = Ln[-Ln(1-F_X)]
DATA VALUE (X-ε)
1000
100
10
1
.02
.05
.10
.20
.50
.90
.99
-5
-4
-3
-2
-1
1
2
WEIBULL QUANTILE (Q)


1.20E+07
1.00E+07
8.00E+06
6.00E+06
4.00E+06
2.00E+06
0.00E+00
TP mass (grams)
March
April
May
June
July
Aug
Sept
1980 Q
1980 Q with 50% dilution
TP 50 ug/L limit
1980 Q with 35% load reduction

East Low Canal Releases to Moses Lake



Moses Lake Volume = 125,000 acre feet

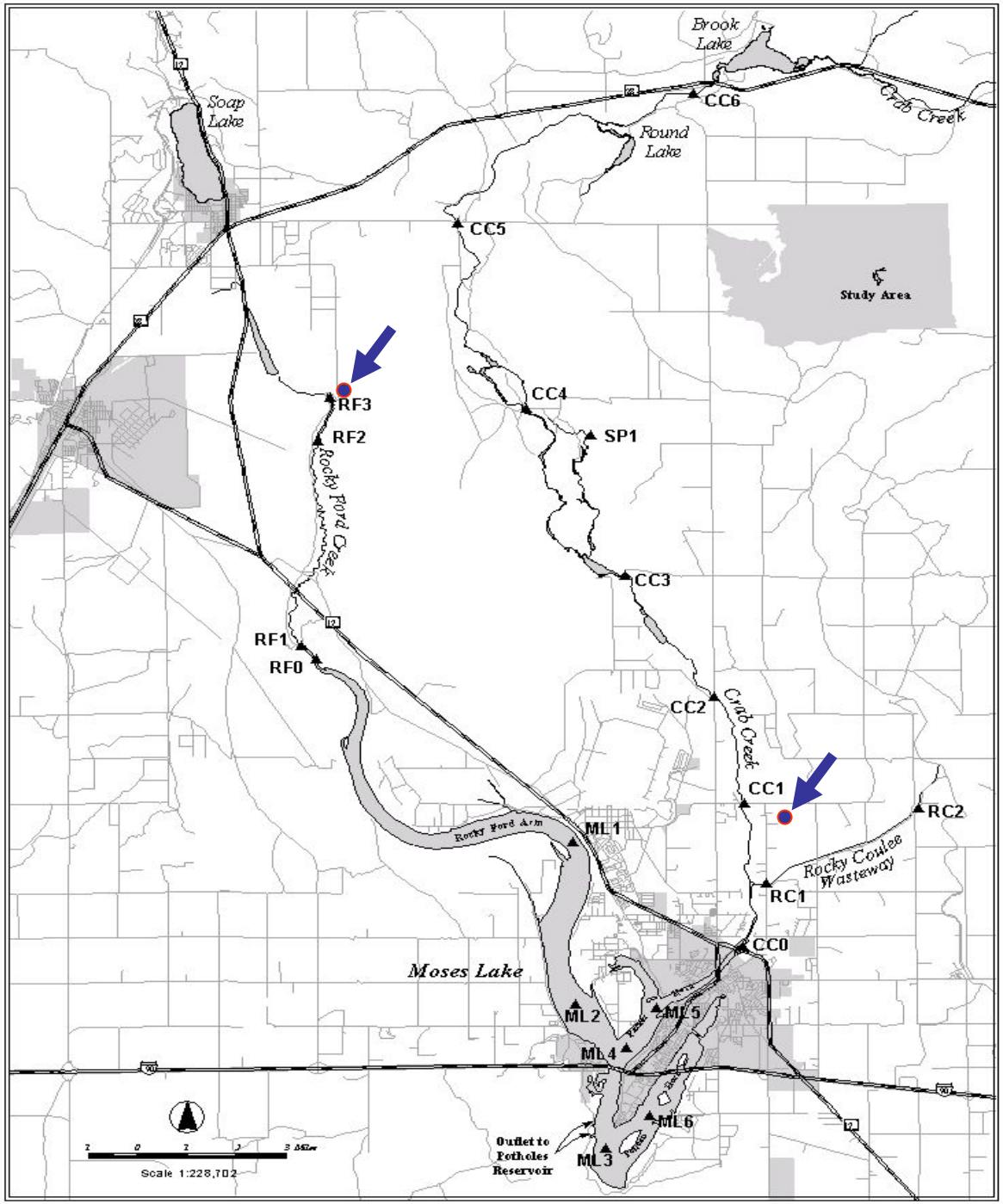

1.20E+07
1.00E+07
8.00E+06
6.00E+06
4.00E+06
2.00E+06
0.00E+00
TP mass (grams)
March
April
May
June
July
Aug
Sept
1980 Q
1980 Q with 50% dilution
TP 50 ug/L limit
1980 Q with 35% load reduction

Phosphorus reduction

- Few point-sources to Moses Lake

Non-point sources

- Episodic winter run-off flows in Crab Creek watershed
- Groundwater sources
  - Increasing urban development sources
  - Agricultural BMPS in local vicinity


Brook Lake
Soap Lake
Round Lake
Crab Creek
CC6
CC5
Study Area
RF3
RF2
CC4
SP1
Rocky Ford Creek
CC3
RF1
RF0
CC2
Crab Creek
CC1
RC2
Rocky Ford Arm
ML1
Rocky Coulee Wasteway
RC1
CC0
Moses Lake
ML2
ML5
ML4
ML6
ML3
Outlet to Potholes Reservoir
Scale 1:228,702

Phosphorus reduction

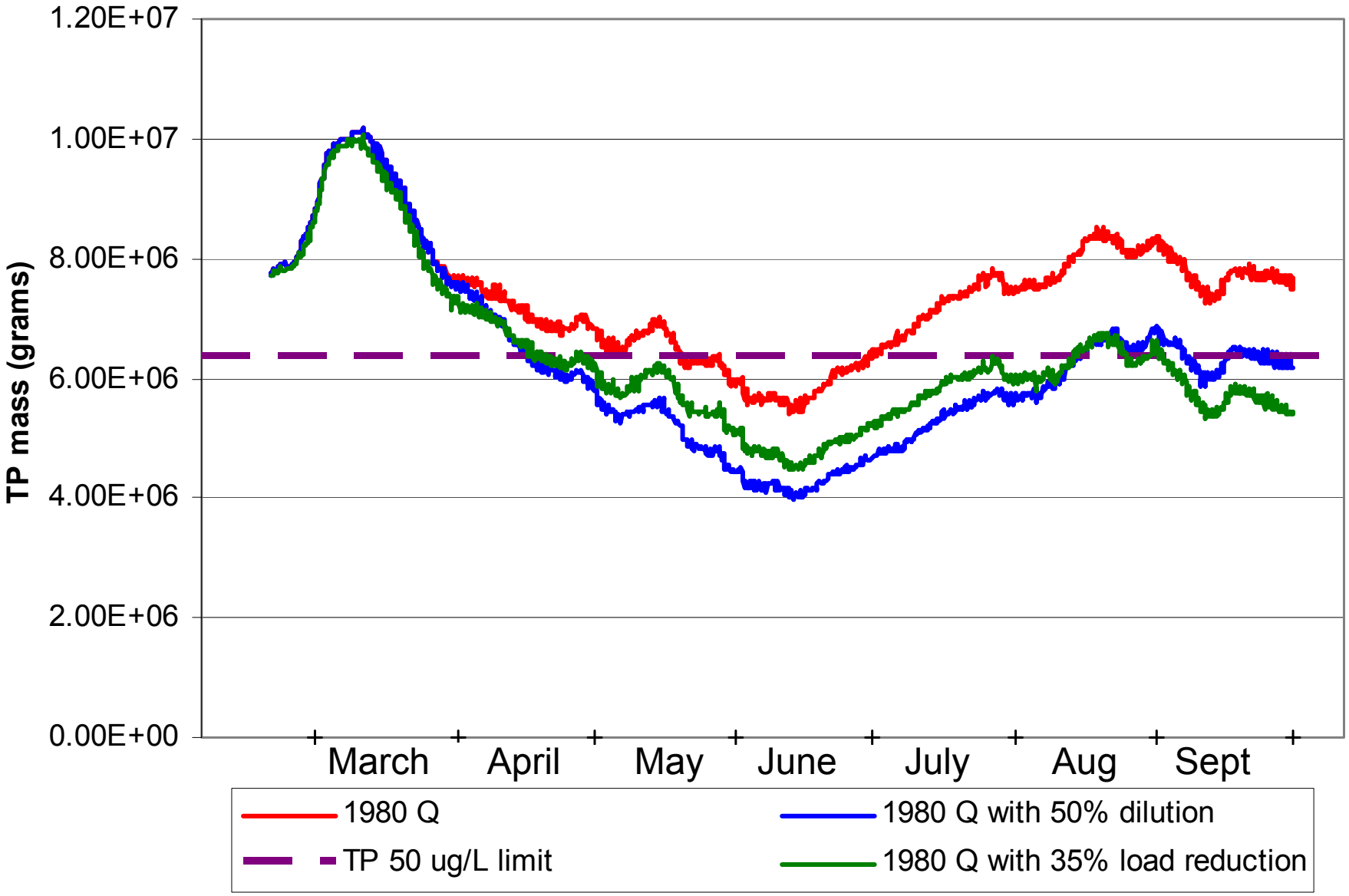
- Few point-sources to Moses Lake

Non-point sources

- Episodic winter run-off flows in Crab Creek watershed
- Groundwater sources
  - Increasing urban development sources
  - Agricultural BMPS in local vicinity

Summary

- 2001 Assessment updates historical work by Dr. Welch and the University of Washington.
- Moses Lake is eutrophic. Phosphorus in the lake should be managed to reduce excessive blue-green algae production in the summer.
- No real noticeable change in concentrations of phosphorus in the watershed tributaries as of 2001.
- Contributions are from many sources and reductions needed from all inputs.
- An across the board 35% reduction from all sources is predicted to meet the 50 ug/L TP criterion most of the time.
- Dilution enhances water quality in Moses Lake when available.


1.20E+07
1.00E+07
8.00E+06
6.00E+06
4.00E+06
2.00E+06
0.00E+00
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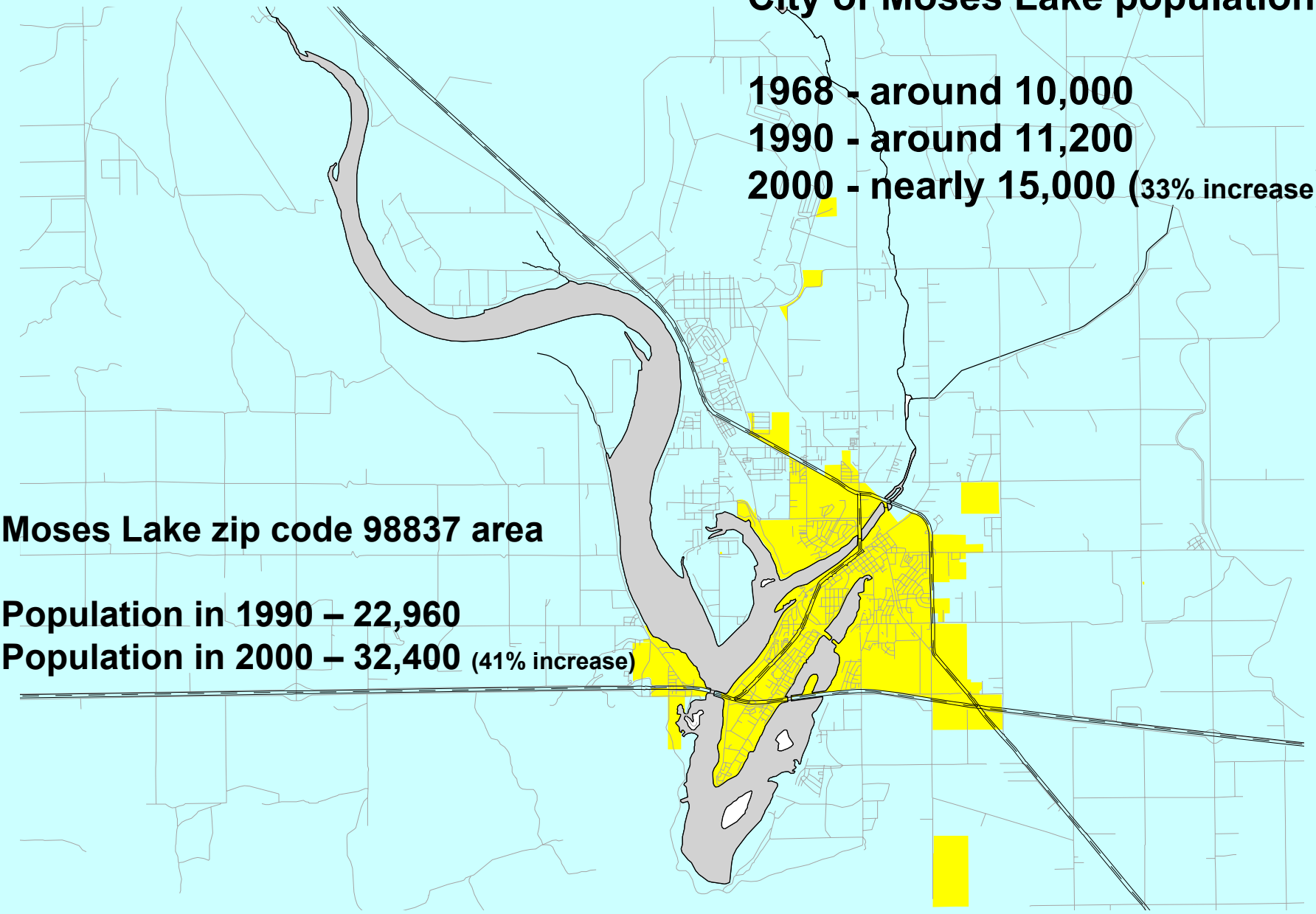
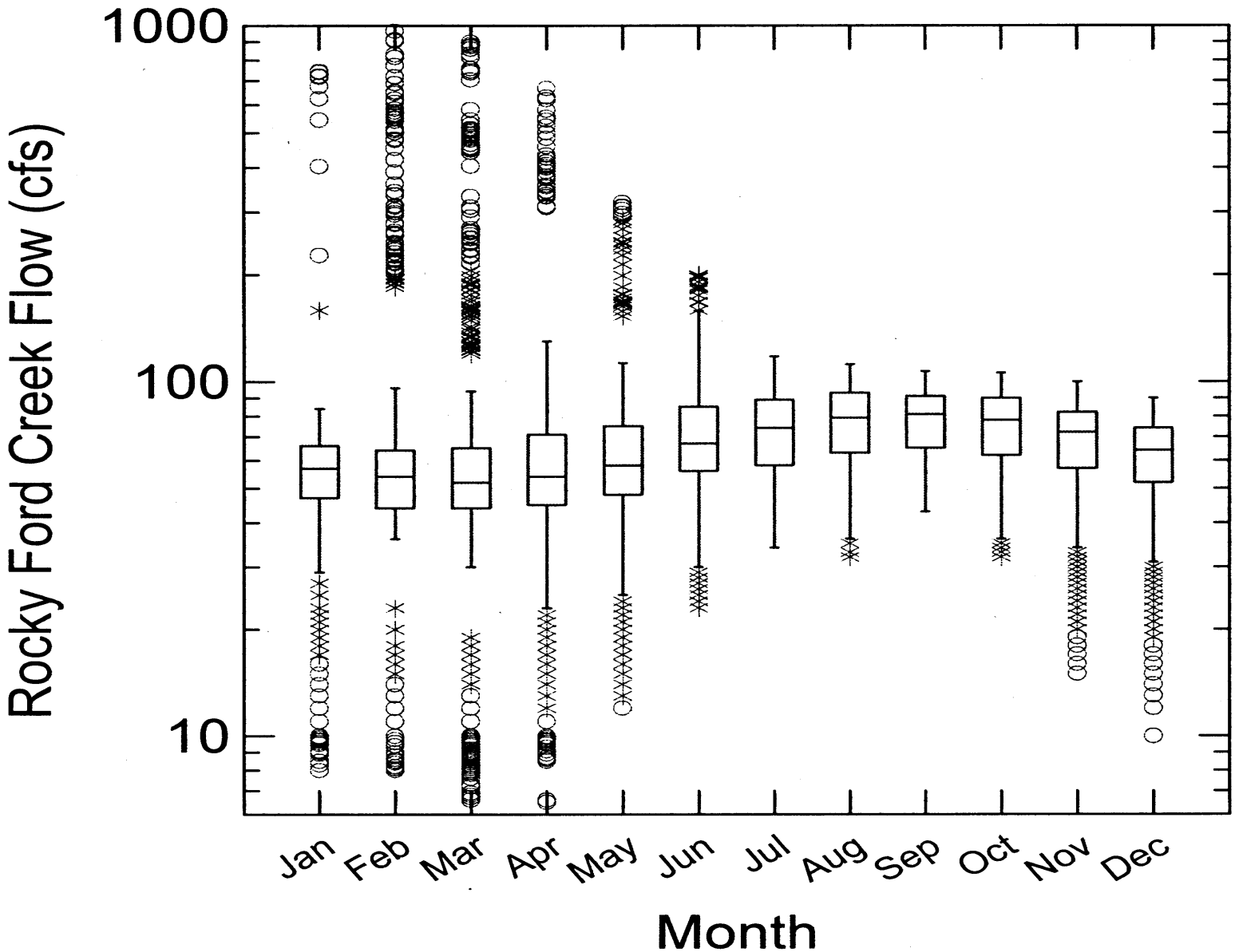
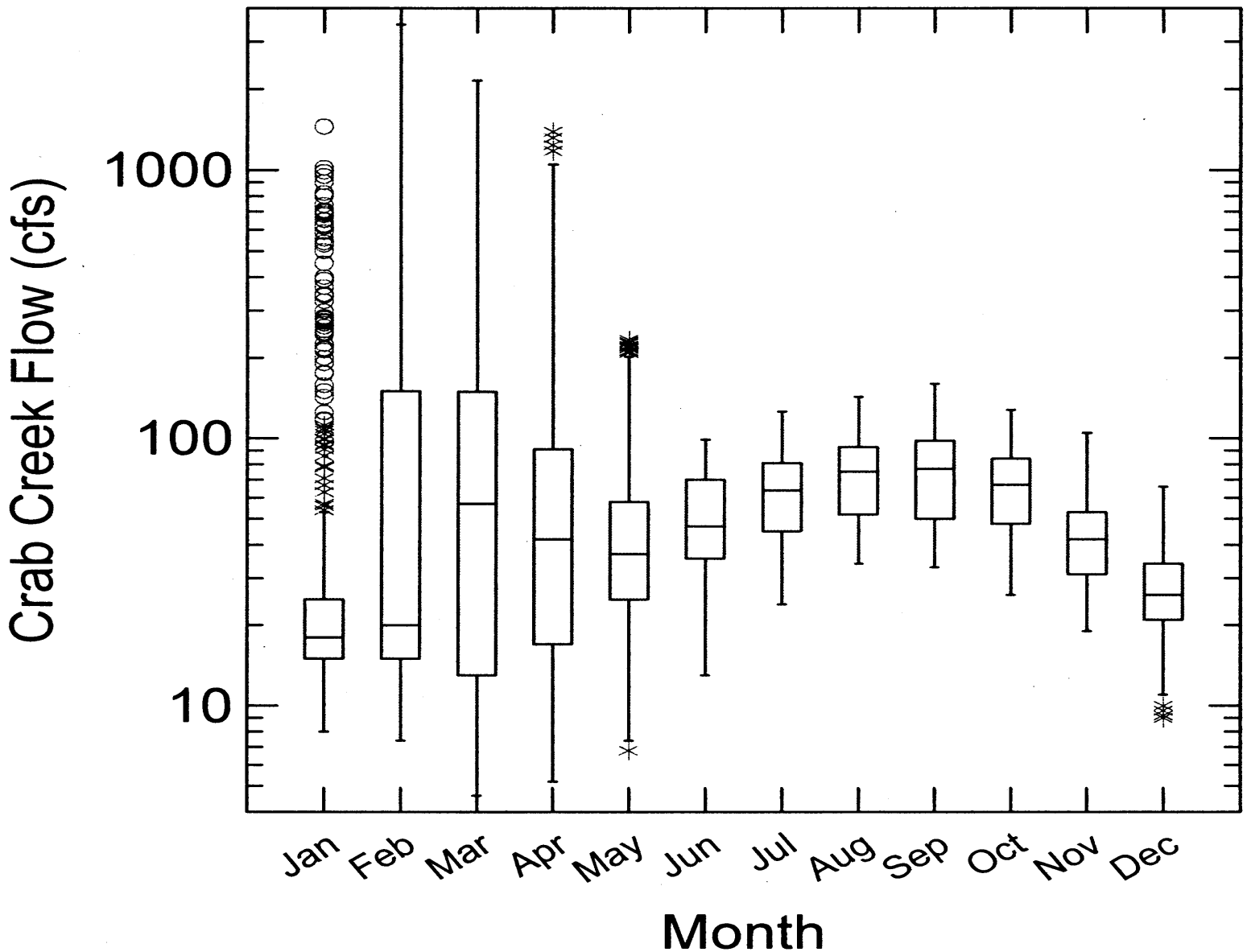

City of Moses Lake population
1968 - around 10,000
1990 - around 11,200
2000 - nearly 15,000 (33% increase)
Moses Lake zip code 98837 area
Population in 1990 – 22,960
Population in 2000 – 32,400 (41% increase)

Rocky Ford Creek Daily Flows (1960-1998)



Crab Creek Daily Flows (1960-1998)