Factoring The Performance of BMPs into the Development of TMDLs for Lake Tahoe

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Project Overview

- Assess current and potential future implementation of stormwater BMPs vs. Lake Tahoe pollutants of concern
- Identify potentially optimal BMPs for load reductions
- Provide rough cost implications and compare to results achieved
- Provide input to monitoring program and watershed modeling

Basinwide Runoff Quality
By Land Use Type

Monitoring data from 32 sites investigated

Constituents	NO3 µg/L	TKN µg/L	SRP µg/L	TP µg/L	TSS mg/L
Undisturbed	6	140*	11	21	3
Residential	47	1405	25	255	142
Commercial	203	2164	114	542	178
Highway	253	1843	100	1208	1133
LRWQCB/TRPA Criteria	500 as Dissolved N	NA	100	100/1000	250

Concentrations exceeding Lahontan and/or TRPA discharge limits

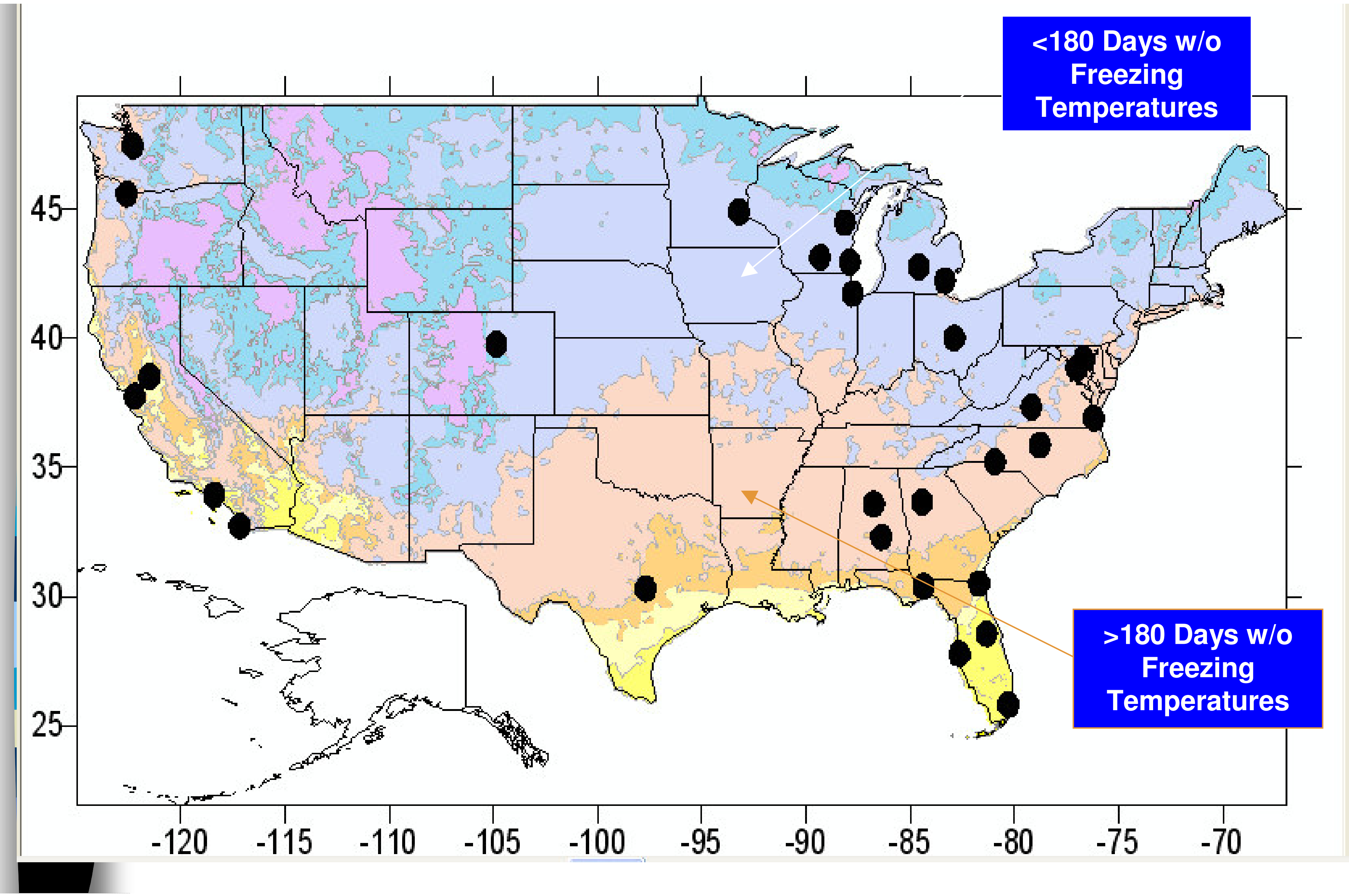
Treatability - Particle Size Distribution limited -Caltrans Data (and now Heyvaert)

Selected Tahoe Specific BMP Effluent Quality

Site	BMP	TSS (mg/L)	TP (ug/L)	DP (ug/L)	NO3-N (ug/L	NH4-N (ug/L)
Cave Rock I	Detention basin	177	232	-	89	-
Blackwood Creek	Enhanced SEZ	5	9	-	24	-
Upper Edgewood	Retention Basin	190	180	-	-	-
Eloise Basin, Industrial Site	Detention Basin	10	227	188	198	16
Northwood Ditch Site	Detention Basin	8	72	38	40	7
Incline Village	Detention Basin	1420	805	560	8	33
Cave Rock II	Rocklined ditch	370	530	-	-	-
Lahontan/TRPA Limits		250	100	100	500 as (NO3-N) + (NH4-N)	

Exceeds Lahontan/TRPA criteria

NSW Database Sites Analyzed Relative to Median Freeze-free Period (Days)



BMP Studies – Cold Regions

- Number of BMPs located in cold regions
  - 144 BMPs in “Warm” Climates
  - 24 in “Cold” Climates
- Number of BMPs with apparent cold season/weather data (by BMP Type)

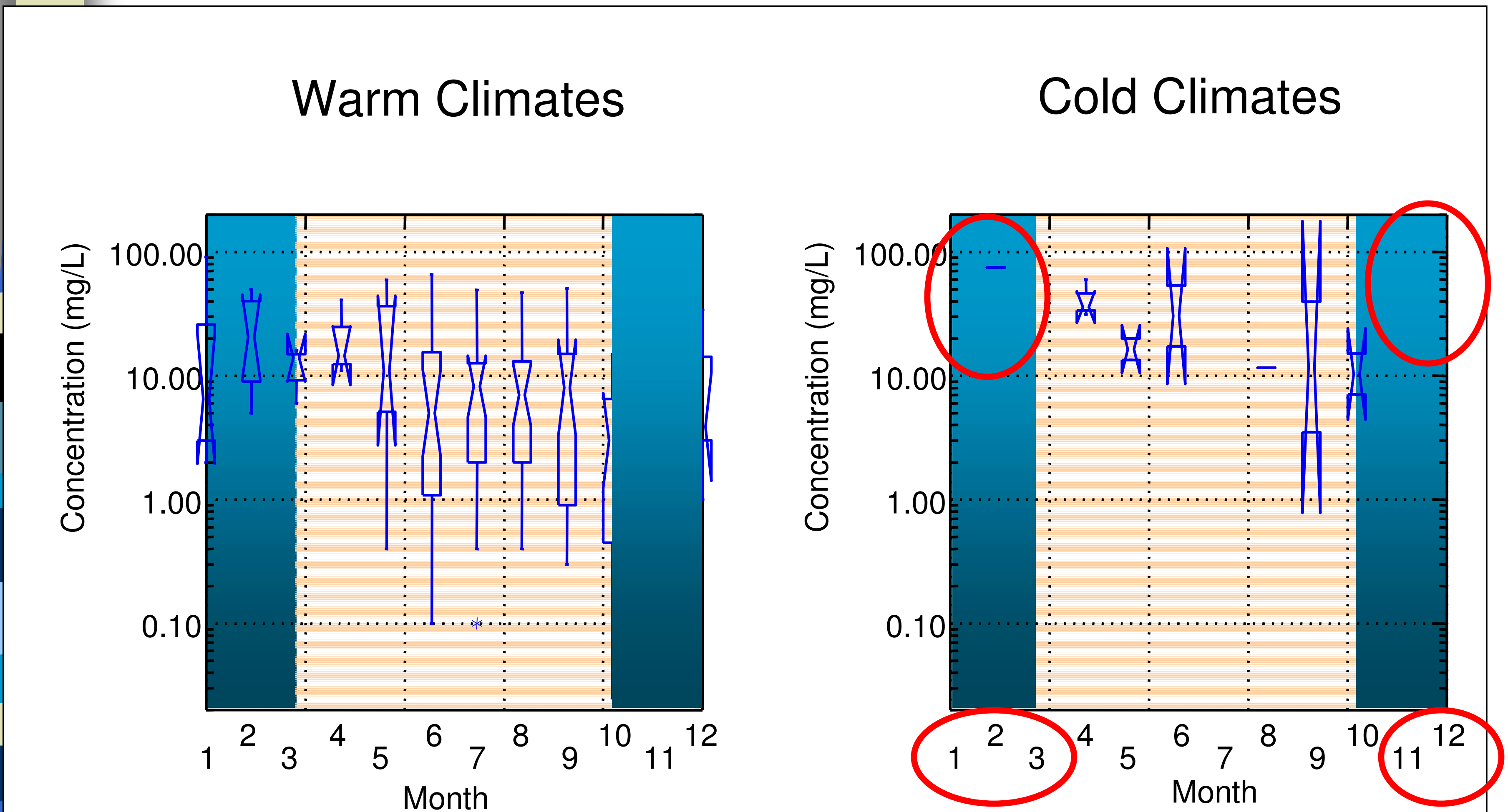
“WARM CILMATE”

BMP Category	Number of BMPs
Detention Basin	22
Biofilter	32
Hydrodynamic Device	15
Media Filter	27
Porous Pavement	4
Percolation Trench/Well	1
Retention Pond	21
Wetland Basin	13
Wetland Channel	9

“COLD CLIMATE”

BMP Category	Number of BMPs
Detention Basin	2
Hydrodynamic Device	3
Porous Pavement	1
Retention Pond	12
Wetland Basin	2
Wetland Channel	4

Wet Pond – Cold Climate TSS Effluent Concentration

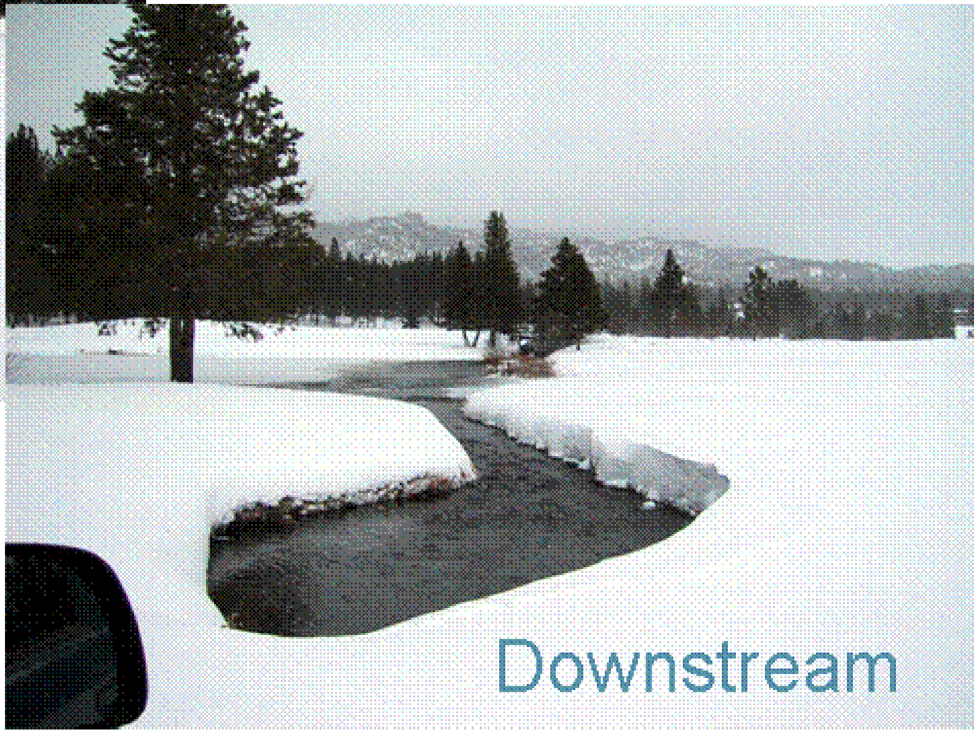


Jan -------------------------- Dec

Jan -------------------------- Dec

Conclusion – Cold Weather BMP Data

- **Conclusion: People don't like to sample when it is cold out.**
  - **Statistically proven**



BMP Effluent Quality Comparison

Constituent	ASCE	TCWTS	Lake Tahoe BMPs Mean Effluent Quality
TSS	26	10	79 (n=22)
TP	210	122	153 (n=20)
DP	70	59	100 (n=11)
NO3-N	300	262	67 (n=20)
NH4-N	148	14	14 (n=12)
TKN	930	749	874 (n=12)

- ACSE Best performing BMPs mean effluent quality
- TCWTS – Tahoe City Wetland Treatment System

Basinwide BMP Effluent Quality Comparison with ASCE/EPA Database

Constituents	Land Use Type: Undisturbed	Roadway	Industrial	Mixed Urban	Residential	Turf Grass	ASCE Database Achievable Mean Effluent Conc.	Achievable % Reduction: Undisturbed	Roadway	Industrial	Mixed Urban	Residential	Turf Grass
TSS	44	498	202	341	142	NA	26	41%	95%	87%	92%	81%	NA
TP	28	878	800	295	325	866	210		76%	74%	29%	35%	76%
DP	30	57	66	224	30	489	70				69%		86%
NO3	2	35	213	256	56	40	300						
NH4	3	156	212	41	35	53	148		5%	30%			
TKN	140	2,443	4,995	NA	1,636	4,795	930		62%	81%	NA	43%	81%

No significant difference between influent and effluent quality

Basinwide BMP Effluent Quality Comparison with Tahoe Data

Constituents	Land Use Type: Undisturbed	Roadway	Industrial	Mixed Urban	Residential	Turf Grass	Tahoe Basin Mean Effluent Conc.	Achievable % Reduction: Undisturbed	Roadway	Industrial	Mixed Urban	Residential	Turf Grass
TSS	44	498	202	341	142	NA	79		84%	61%	77%	44%	NA
TP	28	878	800	295	325	866	153		83%	81%	48%	53%	82%
DP	30	57	66	224	30	489	100				55%		80%
NO3	2	35	213	256	56	40	67			69%	74%		
NH4	3	156	212	41	35	53	14		91%	93%	66%	60%	74%
TKN	140	2,443	4,995	NA	1,636	4,795	874		64%	83%	NA	47%	82%

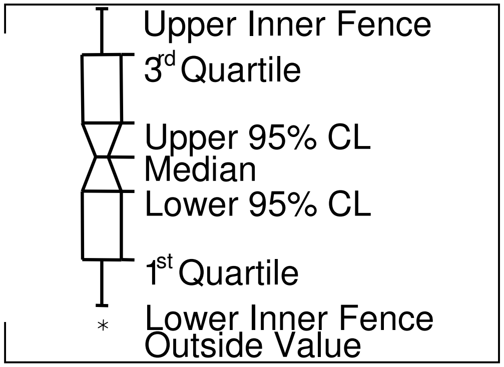
No significant difference between influent and effluent quality

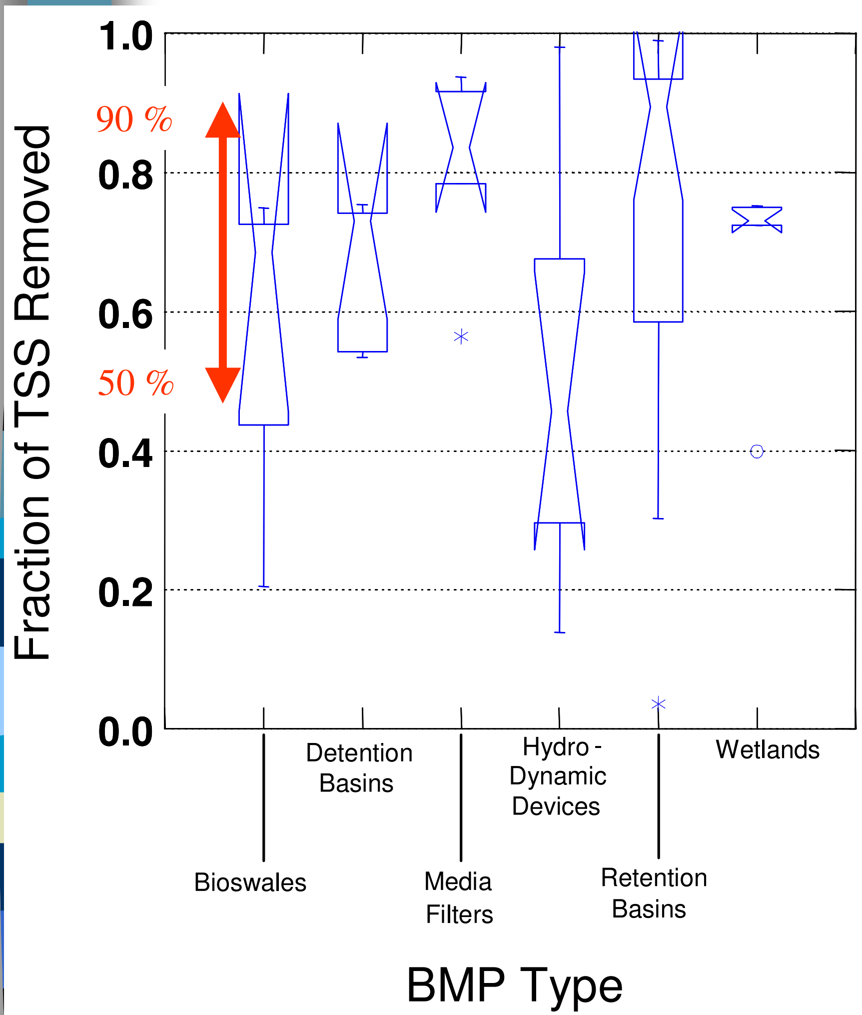
Assessing and Applying BMP Performance[1]

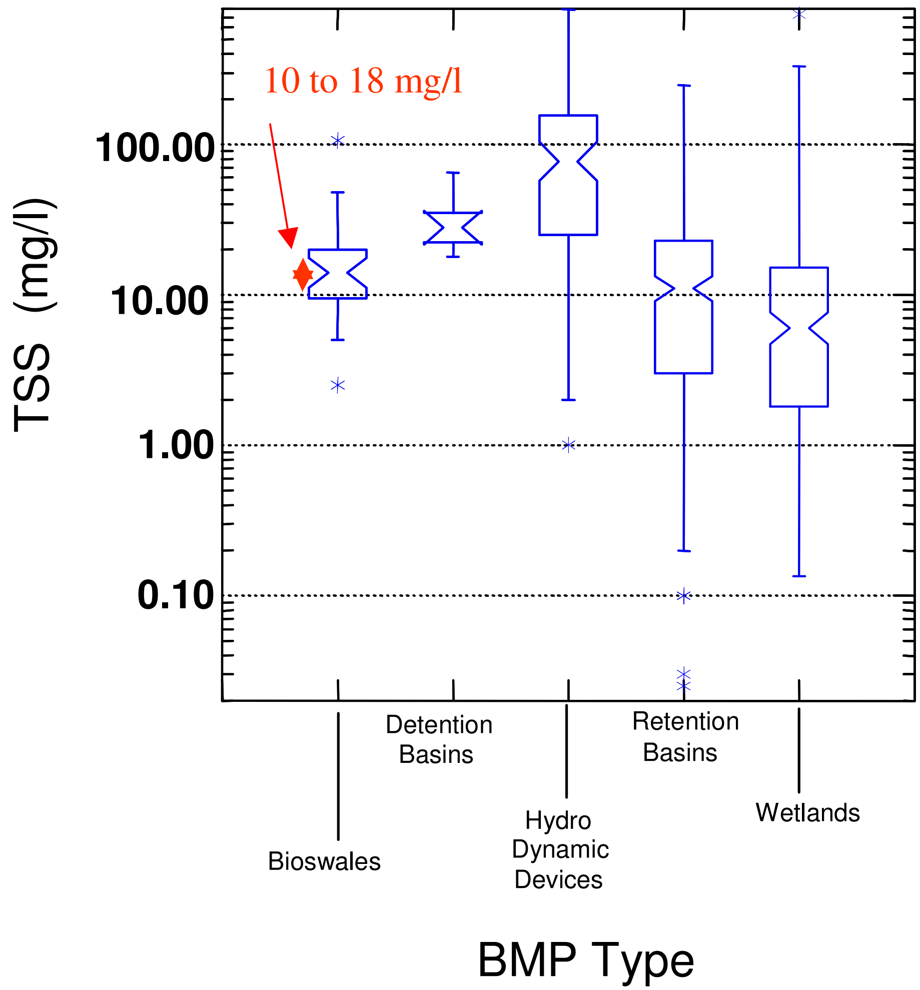
- How much runoff is evapotranspirated or infiltrated? Hydrological Source Control
- How much runoff is treated (and not)?
- What is effluent quality of treated runoff?
- *Does BMP prevent accelerated downstream erosion?*

[1]Strecker, et. al., 2001, 2004

Box plots of the fractions of Total Suspended Solids (TSS) removed and of effluent quality of selected BMP types







Volume Reduction-
Hydrological Source Controls

Some BMPs have benefits over others in terms of volume reduction (From ASCE/EPA Database)

BMP Type	Mean Monitored Outflow/Mean Monitored Inflow for Events Where Inflow is Greater Than or Equal to 0.2 Watershed Inches
Detention Basins	0.70
Biofilters	0.62
Media Filters	1.00
Hydrodynamic Devices	1.00
Wetland Basins	0.95
Retention Ponds	0.93
Wetland Channels	1.00

BMP Performance – Effluent Quality (from ASCE/EPA Database)

DB = Detention Basin (Dry Basin)

GS = Bio-swale/Filter

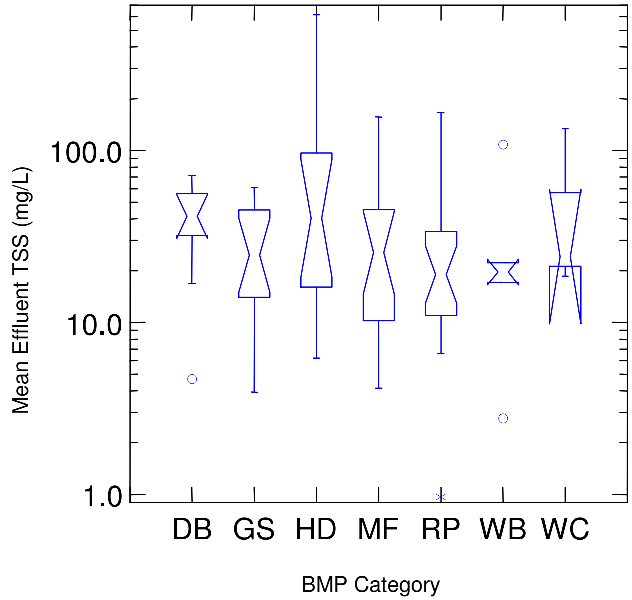
HD = Hydrodynamic Device

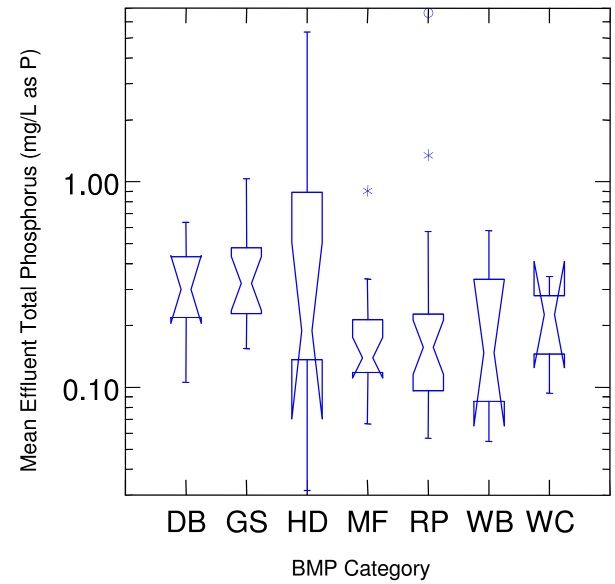
MF = Media Filter

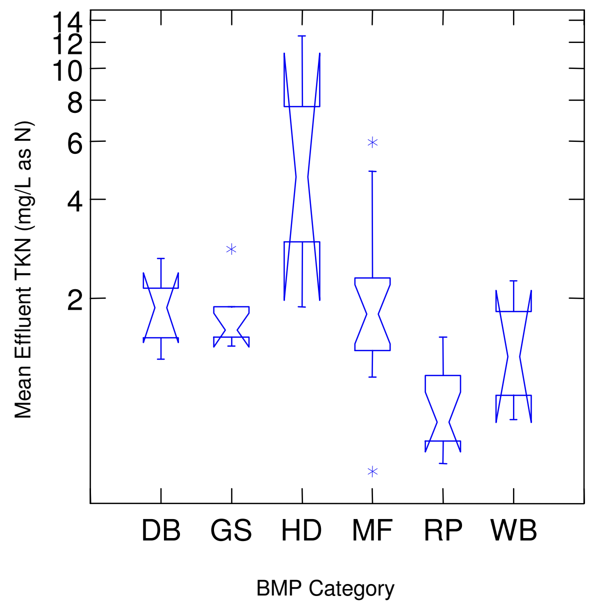
RP = Retention Pond (Wet Pond)

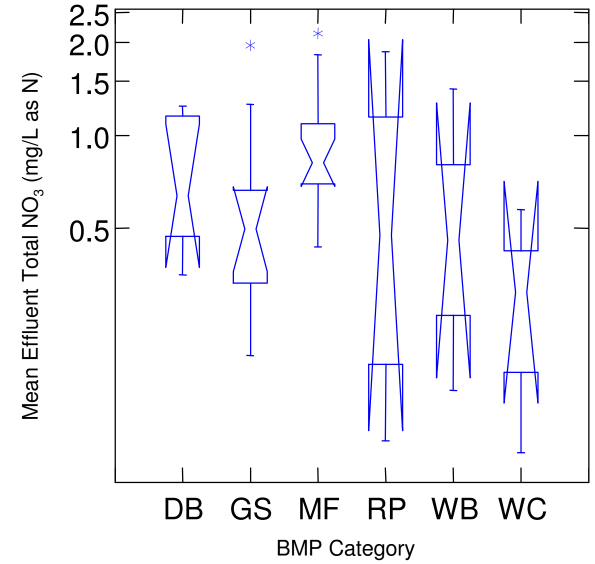
WB = Wetland Basin

WC = Wetland Channel







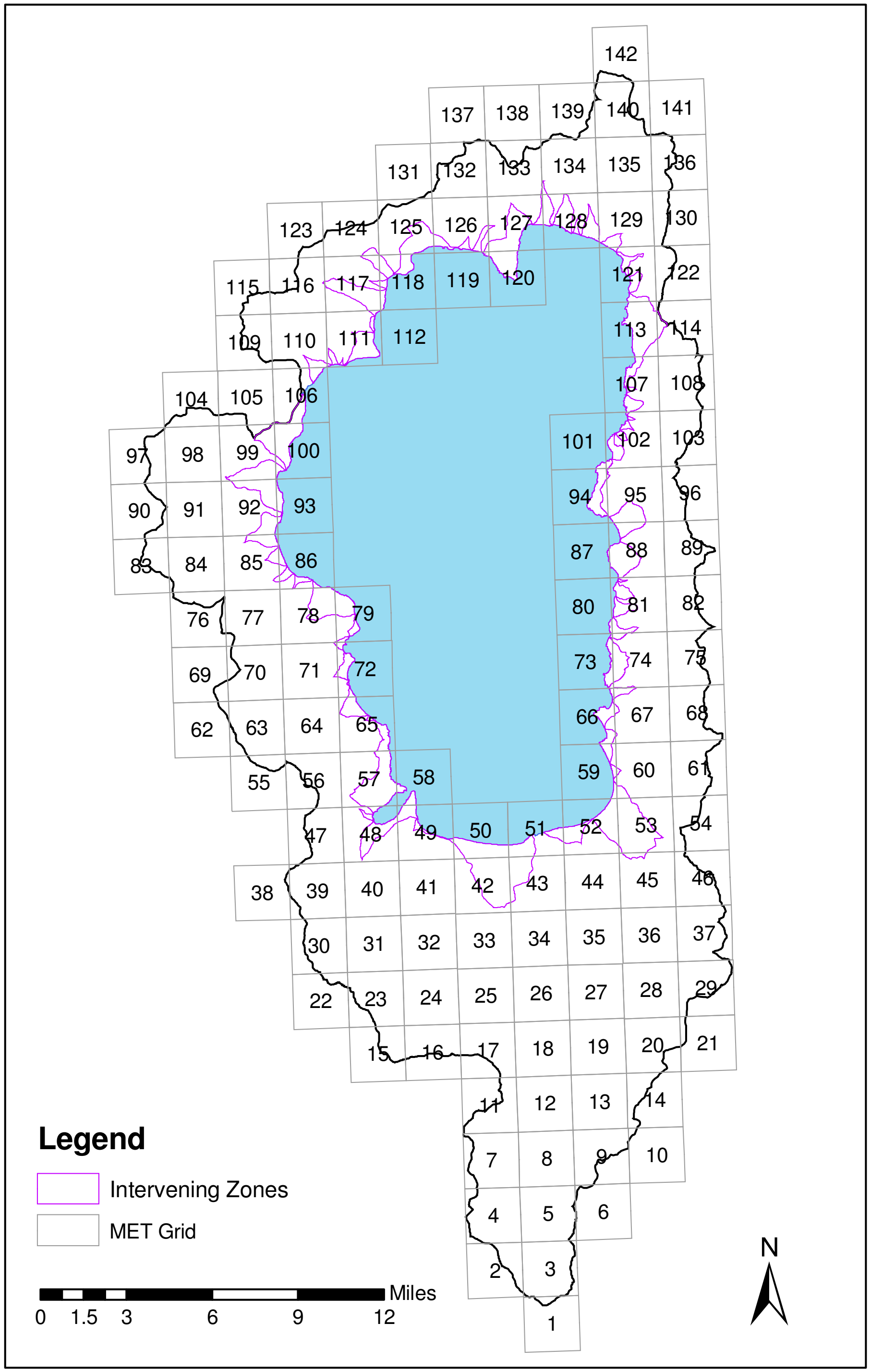


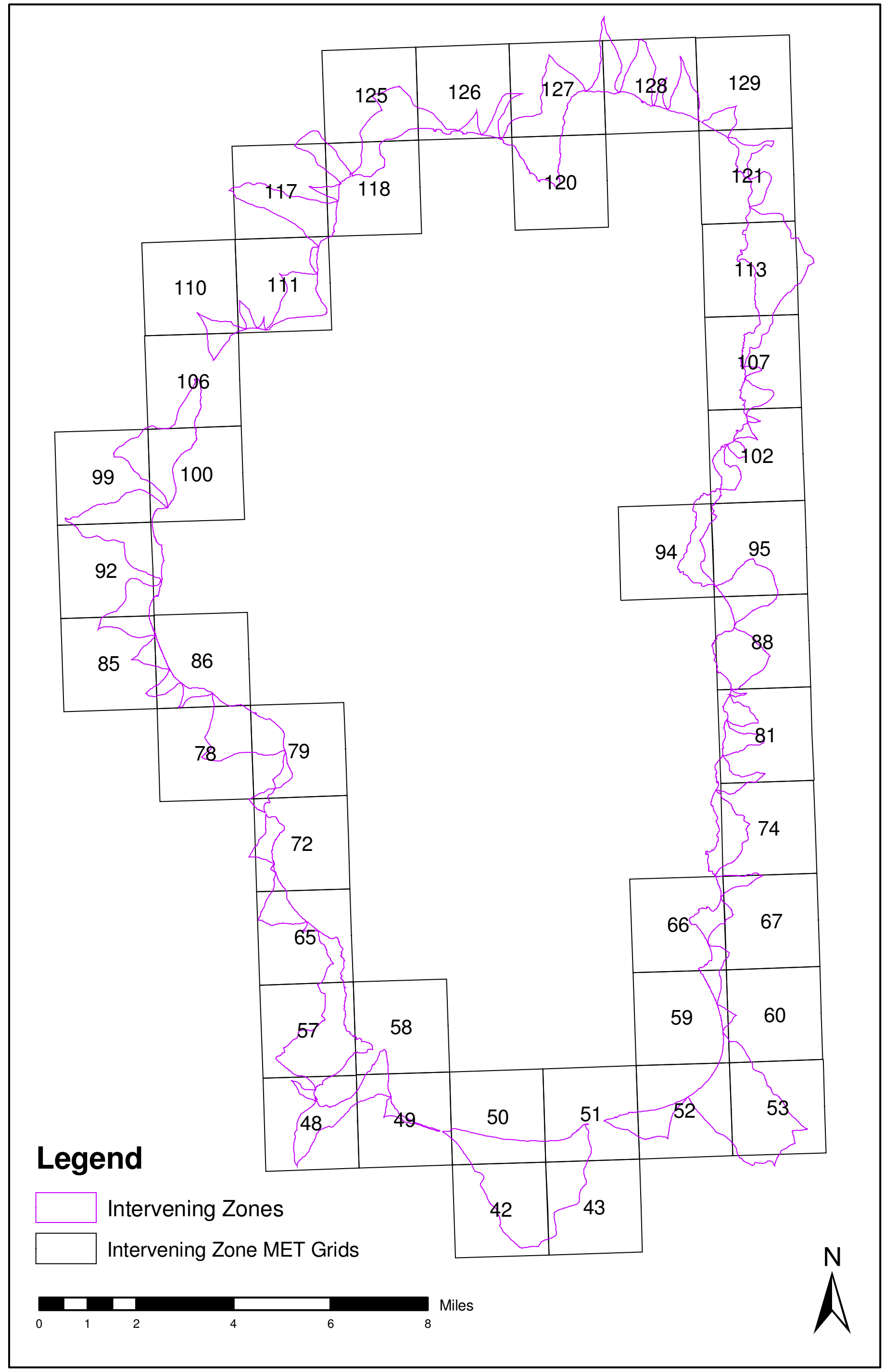
Assess Potential BMP Effectiveness

Continuous SWMM modeling to Assess BMP Performance at a Project Scale

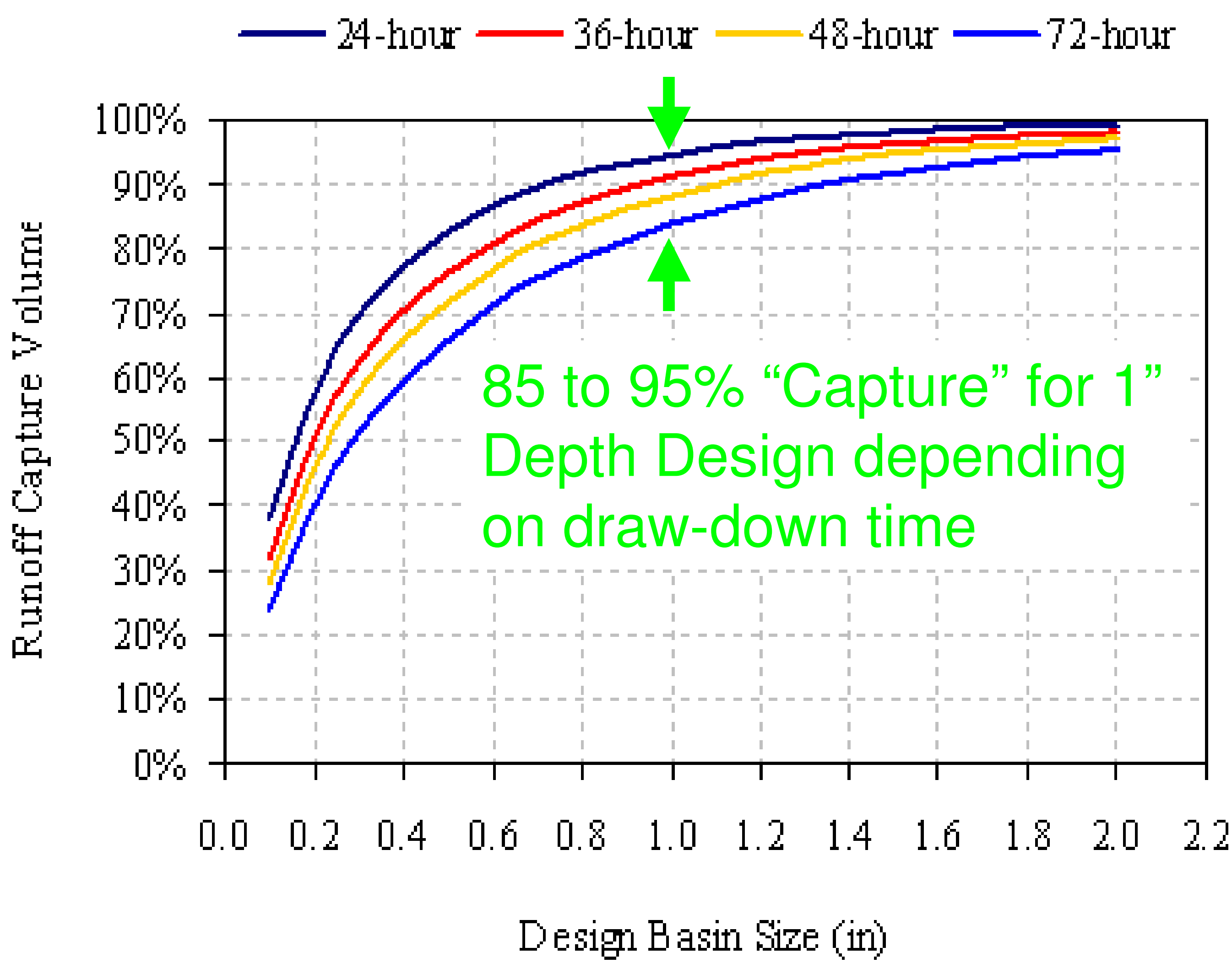
- Developed SWMM model for 43 MET Grids representing mostly urbanized intervening zones

- Used continuous SWMM simulations (period of record - 31 years):
  - Assessed how much runoff from developed, impervious area is captured and /or treated
  - Assessed effects of residence time (drain time) on various sub-classes of fine particulates (e.g. 3, 4, 5, 6.5, 8, 10, 15, 25, 32, 64 microns)
  - Evaluated 20 alternate sizing criteria (0.1” to 2”) for 43 MET grids (The design storm of 20 year 1-hour (approximate depth of 1”) is the current standard used by LRWQCB and TRPA in both permit review and regulations)
  - Generated performance curves for percent runoff captured as well as percent particle treated for all 43 MET grids

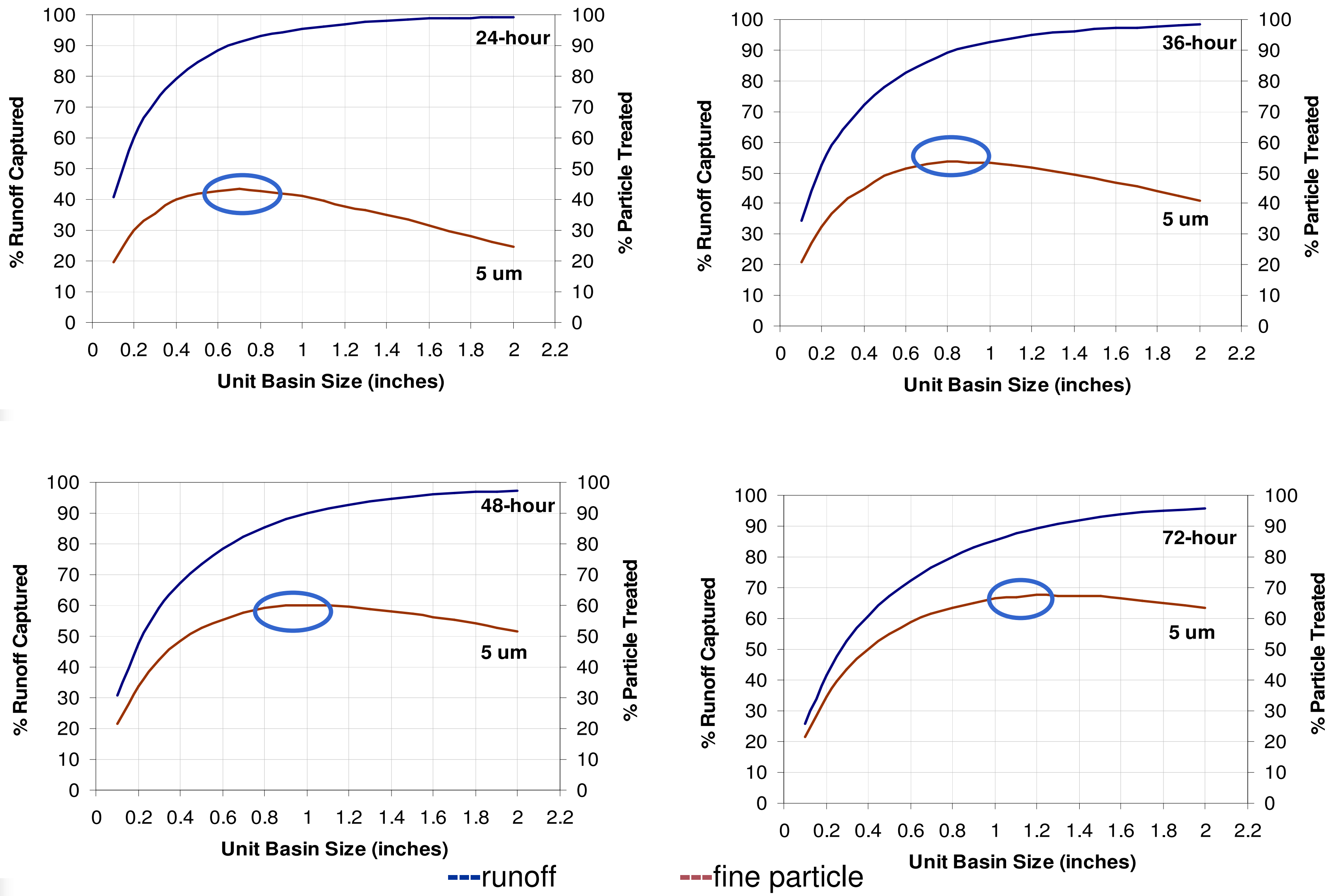

Legend
Intervening Zones
MET Grid
Miles
0 1.5 3 6 9 12
N


Legend
Intervening Zones
Intervening Zone MET Grids
Miles
0 1 2 4 6 8
N

BMP Performance Curves for Various Design Sizes and Draw Down times (Scenario Site, Met Grid 42)



Effect of Sizing and Residence Time on Fine Particle Removal Efficiency



Optimization of Capture Volume (MET Grid 42)

- If the basin were sized for the current standard (1”) the runoff capture volume would be 95%, 93%, 90%, and 86% for 24-hour, 36-hour, 48-hour and 72-hour drawdown times respectively
- The overall sizing criteria appears adequate for this MET grid. However, in some regions with higher annual average precipitation (e.g. MET grid 106) our analysis showed that the same criteria would not be enough to achieve “same level” of treatment
- The importance of additional design criteria (draw-down time) has been demonstrated. For the 1” design capture volume, a 48 to 72 hour draw-down time performed better (60 to 65 percent fine particulates of 5um removal)
- Volume losses are a significant contributor to load reduction – both infiltration and evapotranspiration – for dry BMPs

Stormwater BMP Performance: Basin Wide Implementation

- **Purpose: To estimate and compare average annual runoff volumes, pollutant loads, and pollutant concentrations from the *impervious areas of the intervening zones* prior to and after basin-wide BMP implementation**

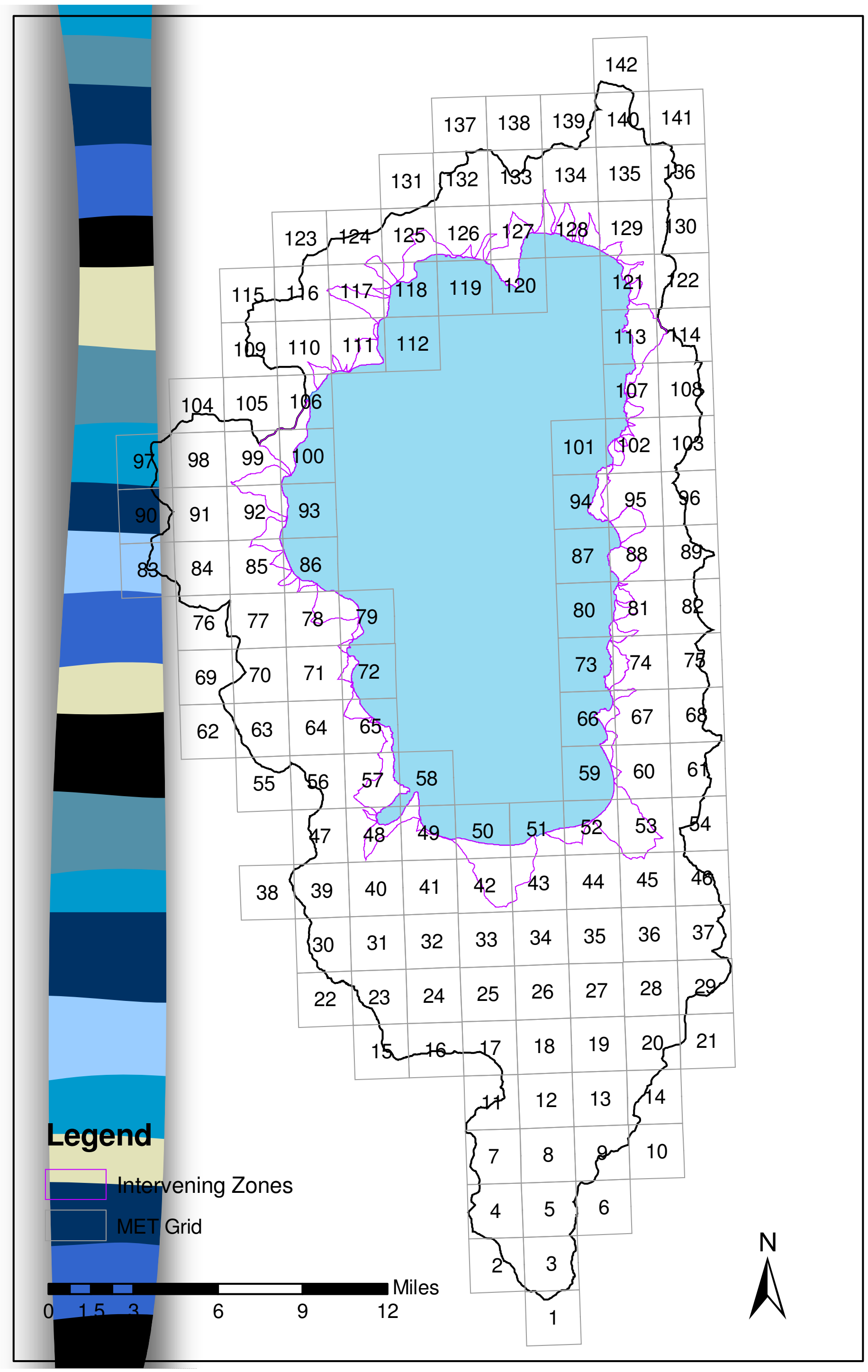
Modeling Approach

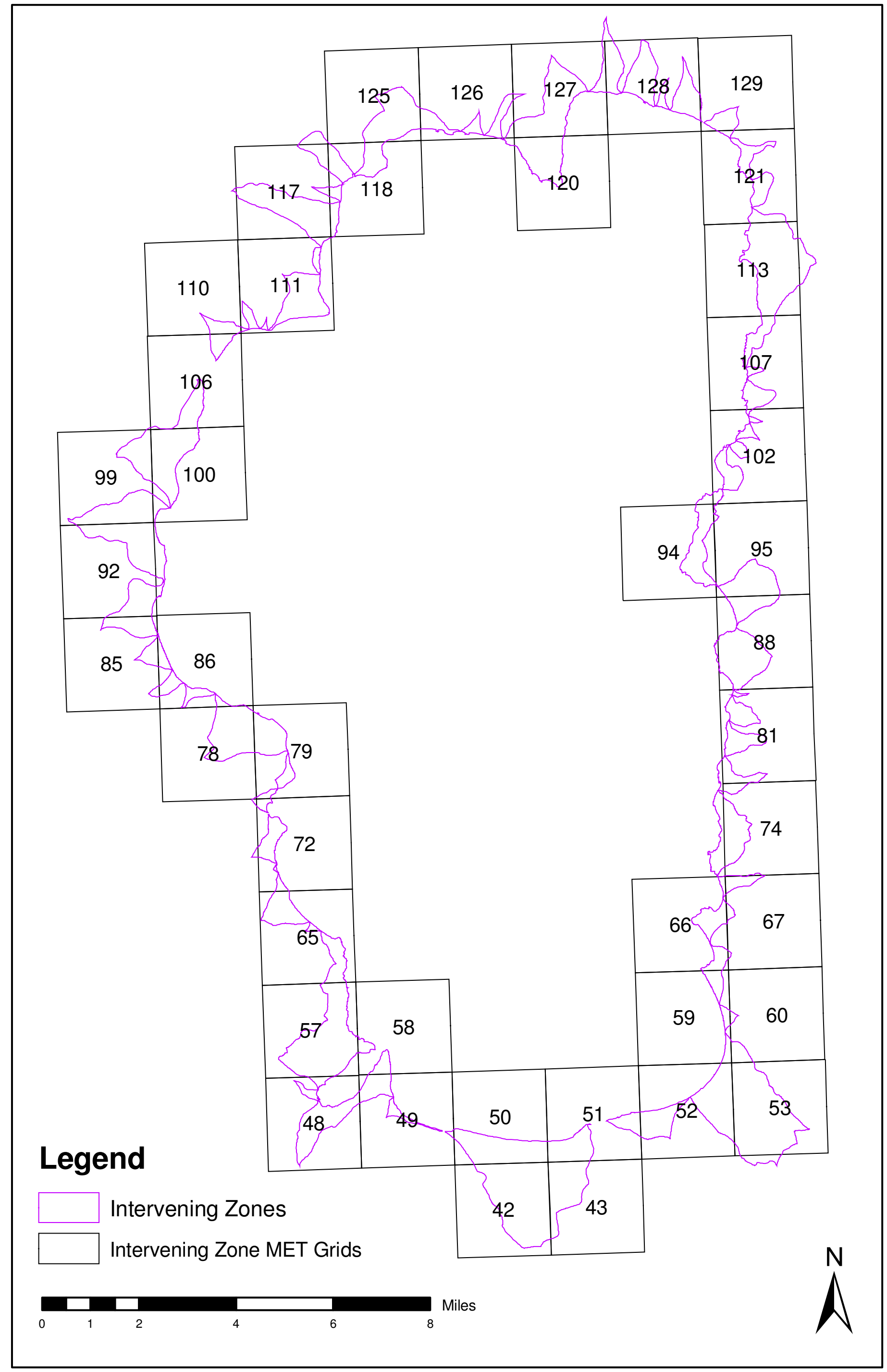
- Modification of an empirical method that has been referred to by others as the Simple Method (Schueler, 1987)
- Utilizes annual runoff volume estimates and land use-based pollutant EMCs to predict:
  - average annual pollutant loadings
  - average pollutant concentrations
  - BMP performance based upon Project Analyses (SWMM Modeling)
- Implemented in ArcGIS™ ArcView 8.3 software using a 10-meter grid

GIS Data Pre-Processing

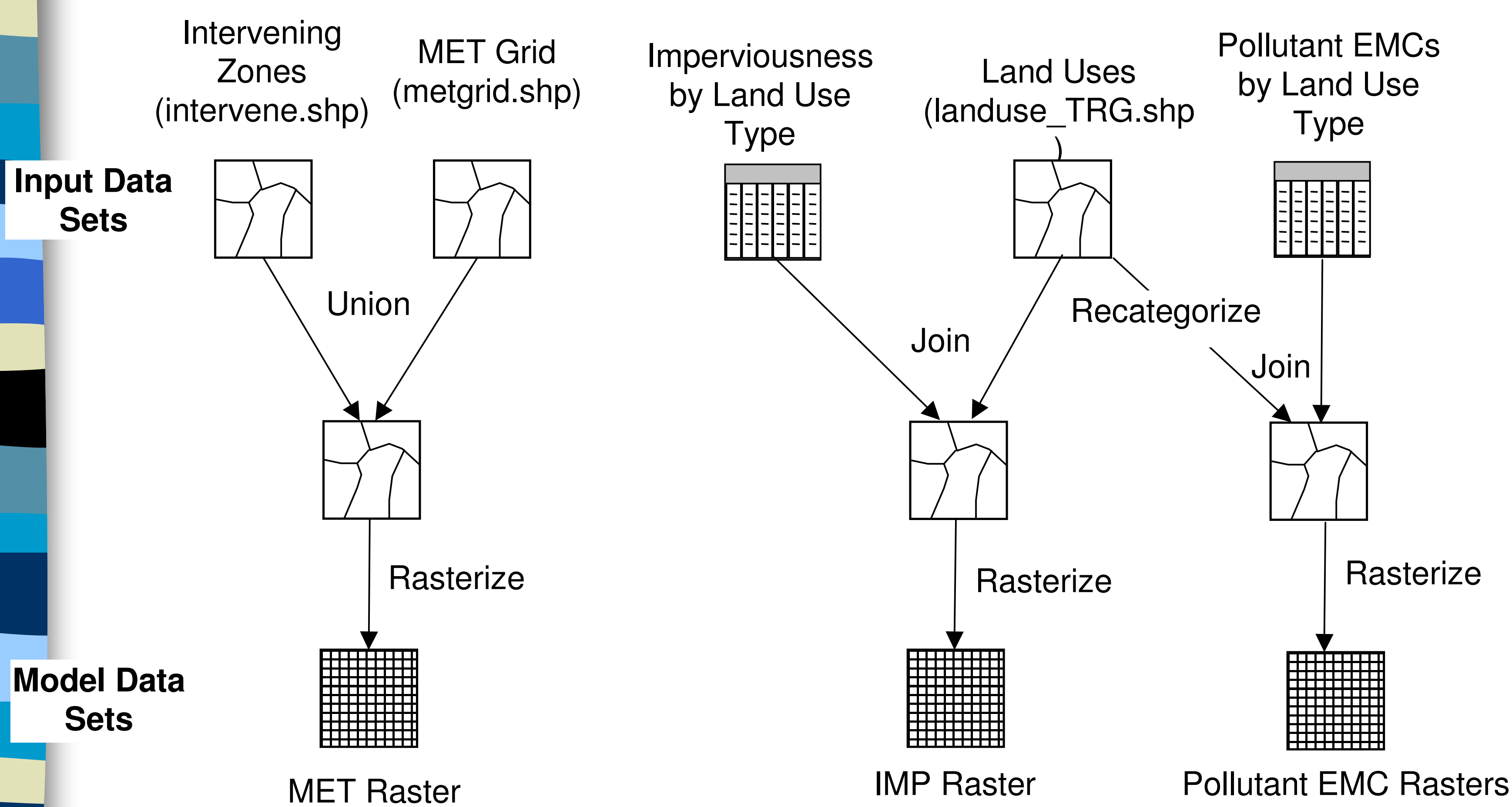
Initial Data Layers

Name	Description	Type	Source
intervene.shp	Intervening watershed zones	Polygon shapefile	TRPA
metgrid.shp	Meteorological grid	Polygon shapefile	Tetra-Tech
landuse_TRG.shp	Land use	Polygon shapefile	TRG


Legend
Intervening Zones
MET Grid
Miles
0 1.5 3 6 9 12
N


Legend
Intervening Zones
Intervening Zone MET Grids
Miles
0 1 2 4 6 8
N

Pre-Processing Steps



Average Annual Runoff Volume Estimation

$$Q_i = D_i \times A_i \times I_i \times CF_1$$

Where: Q_i = *runoff volume (ft^3) from grid cell i*
D_i = *runoff depth (inches/impervious area) from grid cell i from SWMM output*
A_i = *area of grid cell i (100 m^2)*
I_i = *percent imperviousness of grid cell i*
CF_1 = *conversion factor to convert inches to meters*

Annual Loading Estimation

$$L_{Dj} = \sum_{i=1}^{n} L_i = \sum_{i=1}^{n} (EMC_i) \times (Q_i) \times (CF_2)$$

Where: LD_j = total average annual load (lbs) from drainage area j

L_i = load (lbs) from grid cell i

EMC_i = event mean concentration (mg/L) from grid cell i

Q_i = runoff volume (ft3) from grid cell i

CF_2 = conversion factor to convert mg/L to lbs/ft3

n = total number of cells in drainage area j

Basin-Wide BMP Implementation

- Assumptions:
  - Basin-wide BMP implementation would treat 100% of impervious area runoff of the intervening zones
  - Overall load reduction estimated is a function of the percent capture volume and either the ASCE BMP Database effluent quality or particle settling theory (for TSS only)
  - If influent EMC is less than effluent quality, zero treatment is assumed (i.e., no negative removals)
  - Average particle size distribution reported by Caltrans (2002) is representative of impervious surface runoff in intervening zones (Note these data were the only data available at the time.)

Basin-Wide Detention Basin Implementation Scenarios

Scenario Number[1]	Design Size	Drawdown Rate	Assumed Captured Volume Loss and Wet Pool Volume (WD only)
DD1	**1-inch**	**36-hour**	**15%**
DD1-A[2]	**1-inch**	**36-hour**	**100% Type A Soils, 30% B, 15% C&D**
DD2	**1-inch**	**72-hour**	**15%**
DD3	**Variable[3]**	**36-hour**	**15%**
DD4	**Variable[3]**	**72-hour**	**15%**
WD1	**1-inch**	**36-hour**	**0%, 1% or 0.01-inch wet pool**
WD1-A	**1-inch**	**36-hour**	**0%, 5% or 0.05-inch wet pool**

1 DD is dry detention basin and WD is wet detention basin
2 This scenario is intended to simulate infiltration in the basin
3 Based on optimization of percent capture and removal of 4µm particles

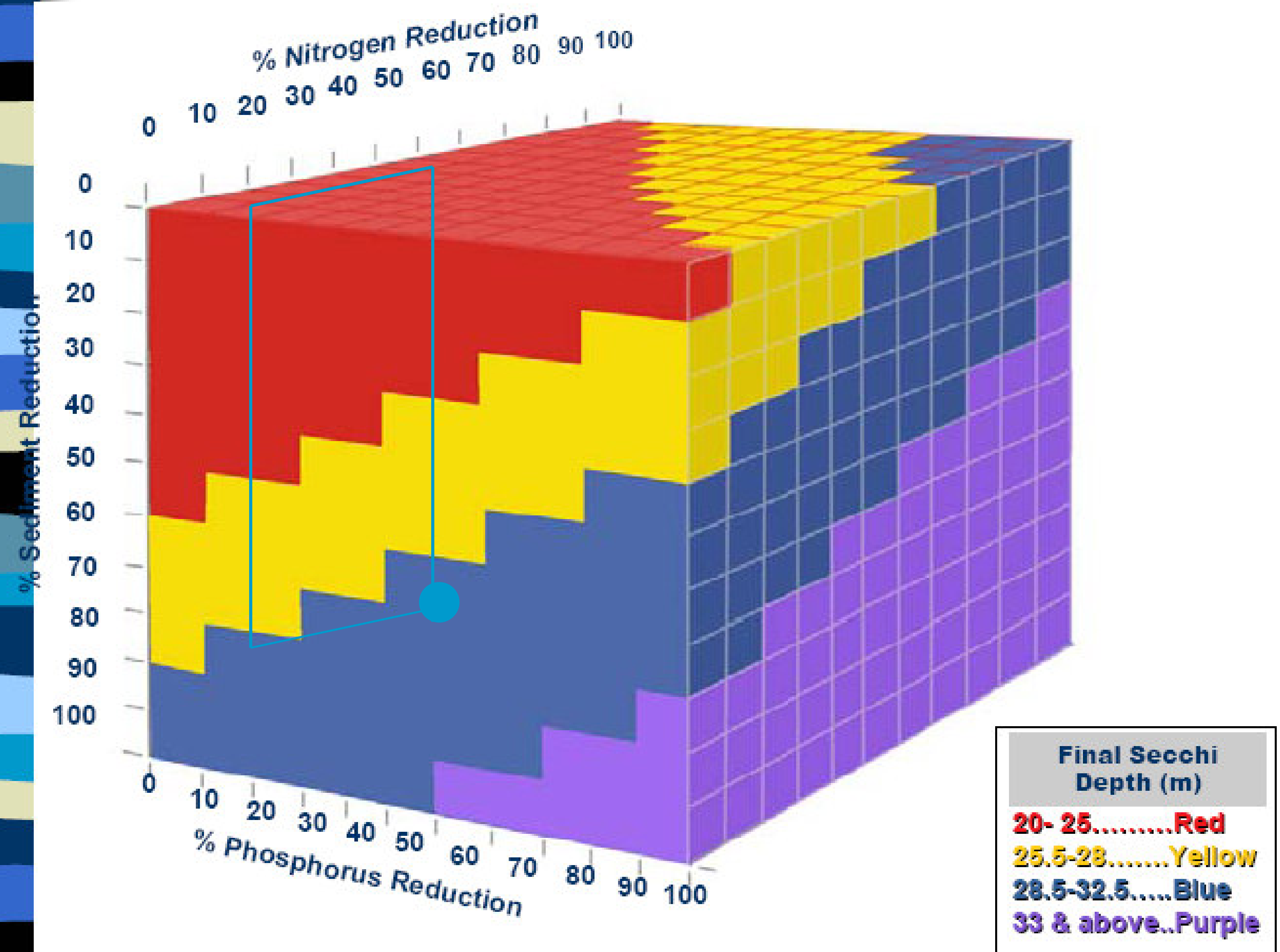
Basin-Wide Percent Load Removal

Effluent Quality Method

	DD1 % Removed	DD1-A % Removed	DD2 % Removed	DD3 % Removed	DD4 % Removed	WD1 % Removed
TSS	81%	83%	74%	81%	81%	85%
TP	47%	59%	43%	48%	47%	60%
DP	30%	47%	27%	30%	30%	11%
TN	14%	35%	13%	14%	14%	23%
NO3	13%	34%	12%	6%	6%	32%

Note: Scenario WD1-A results are identical to WD1 results, so they are not shown

Conceptual Model – Load Reduction Possibilities



Basin-Wide
Load Reduction Possibilities

- Estimated load reductions are highly conservative as only impervious area runoff from intervening zones were included in our model
- When applied to the same size drainage area including pervious area runoff the load reductions should be higher especially for nutrients (applying ASCE/EPA effluent quality)
- When implemented basin-wide, TSS load reduction should meet the treatment goal (for urban areas) with well designed, constructed and maintained conventional BMPs
- Applying physical and chemical treatment methods that provide a better effluent quality for dissolved phosphorus the overall treatment goals for the basin could be met
- For nitrogen, treatment goals are hard to meet as atmospheric deposition is its main source. Only wet ponds and granulated carbon filtration show any significant reduction for stormwater runoff treatment.

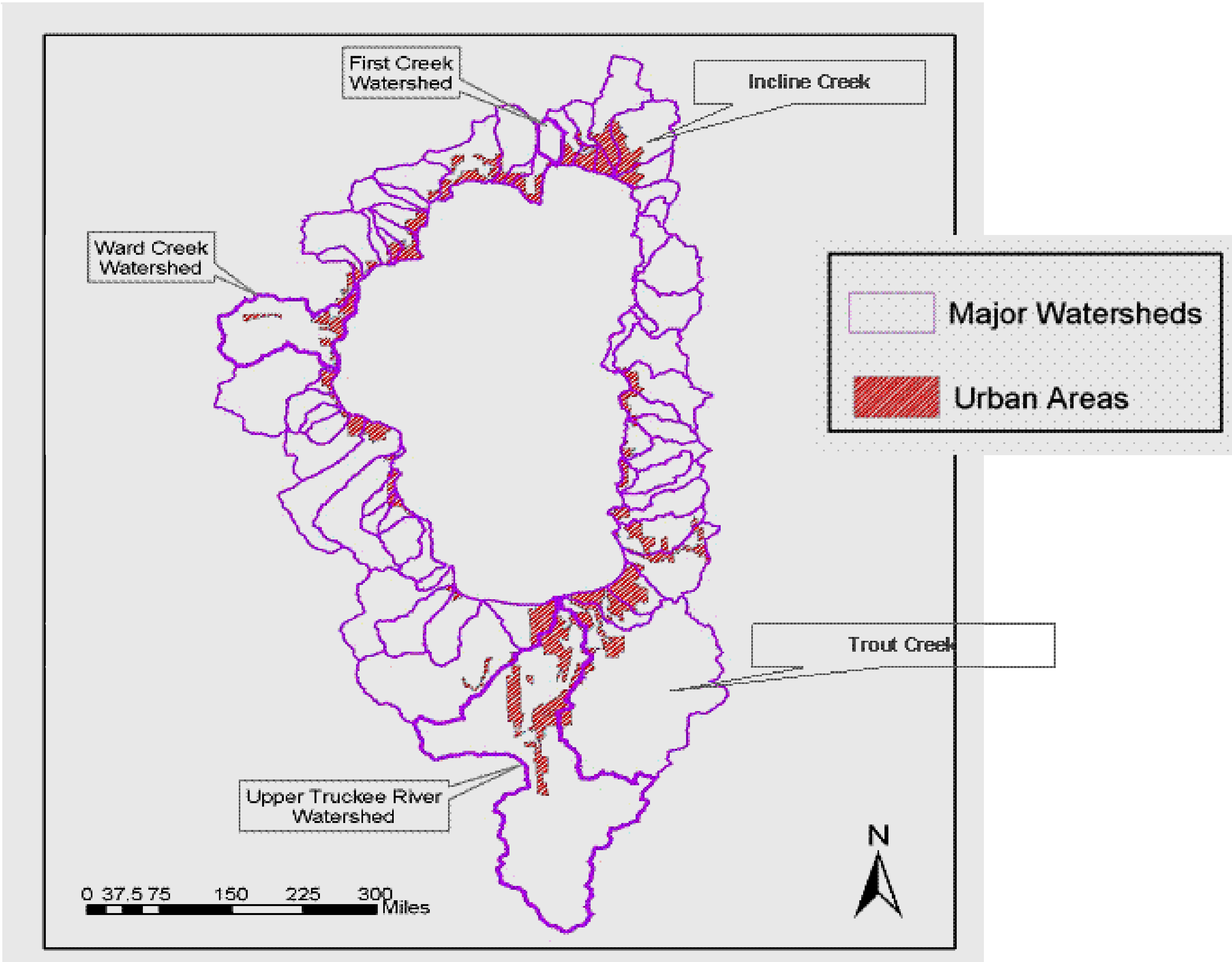
Basin-Wide Percent Load Removal

Particle-Settling Theory Method (TSS only)

Size Range (um)	DD1 % Removed	DD2 % Removed	DD3 % Removed	DD4 % Removed	WD1 % Removed	WD1 % Removed
< 3	23%	38%	24%	40%	51%	71%
3-5	38%	53%	39%	55%	64%	82%
5-8	55%	64%	56%	65%	77%	87%
8-12	60%	66%	62%	66%	87%	87%
12-15	60%	66%	62%	66%	87%	87%
15-25	60%	66%	62%	66%	87%	87%
> 25	87%	81%	87%	86%	87%	87%
Total	61%	64%	61%	67%	77%	83%

Note: Scenario DD1-A results are identical to DD1 results, so they are not shown

Lake Tahoe -Major Watersheds and Urban Areas



Estimated Reductions with Implementation of Scenario DD1A- Dry Extended Detention Basins with Infiltration in the Basin

Parameters	DD1A % Removed from Intervening Zones	DD1A % Removed from the whole Tahoe Basin[a]	WD1 % Removed from Intervening Zones	WD1 % Removed from the whole Tahoe Basin[a]
TSS	83%	41.5%[b]	85%	42.5%[b]
TP	59%	19.5%	60%	19.8%
DP	47%	9.4%	11%	2.2%
TN	35%	3.5%	23%	2.3%
NO3	34%	3.4%[c]	32%	3.2%[c]

[a]Estimated based on TN, TP, DP load contributions by direct runoff from intervening zones to the lake (Reuter and Miller, 2000)

[b]Estimated assuming 50% of the TSS loads to the lake is through direct runoff from Intervening Zones

[c]Estimated assuming NO3 loads would be similar to TN loads

Financial Analyses Tasks

- Estimate average costs for individual BMPs, including life-cycle and initial and operating costs
- Determine rough estimates of basin-wide costs

Basin-Wide Implementation Costs

	Total 30-year Cost	Imp. Area 30-yr Cost ($/imp. acre)	TSS Load Reduction Cost ($/lb TSS) - Effluent Quality	TSS Load Reduction Cost ($/lb TSS) - Settling Theory	Unit TSS Load Reduction Cost ($/lb Particles < 8 µm) - Settling Theory
DD1	$ 53.6M	$ 9,352	$ 0.38	$ 0.50	$ 75.70
DD2	$ 53.6M	$ 9,352	$ 0.41	$ 0.47	$ 54.04
DD3	$ 51.6M	$ 8,996	$ 0.36	$ 0.48	$ 71.36
DD4	$ 62.7M	$ 10,943	$ 0.44	$ 0.53	$ 61.16
WD1	$ 75.0M	$ 13,084	$ 0.53	$ 0.51	$ 46.03

Conclusions and Recommendations

BMP Performance Evaluation

- BMPs are potentially able to meet existing criteria for the TSS and DP (per International BMP database) with selected BMP types and longer detention times
- TP and TN appear more problematic to treat to levels below discharge limits (although high %removal is shown) through conventional BMPs
- Enhanced treatment including physical chemical treatment for TP (alum injection systems, soft liming) and TN (granulated carbon) has shown promise in reducing them to levels below required criteria
- Comparison with 25th percentile values of International BMP database and values monitored from TCWTS study show TP levels could be reduced below criteria by wet detention ponds (wet ponds would have to be well designed)
- Volume reduction (using suitable hydrological source controls) could significantly reduce runoff volumes and therefore pollutant loads

Conclusions of Basin-Wide Evaluation

- Dry ponds provide the greatest removals of dissolved constituents because of volume losses
- Wet ponds provide greatest removals of fine sediments because of increased residence times
- BMPs designed to optimize both volumetric percent capture *and* hydraulic residence time for a particular site are the best performers and the most cost effective
- A 72-hour drawdown rate with larger basin sizes is the most cost effective on a cost per pound of fine sediment (<8 microns)

Recommendations

- Provide more specific criteria for allowed BMPs to treat fine particulates and nutrients
  - Adjust the sizing and operational (e.g. drain times) requirements of BMPs to increase performance
  - Consider "treatment train" with appropriate treatment processes to address particular pollutants
  - Emphasis on BMPs that reduce runoff volumes by infiltration and evapotranspiration (hydrological source control)
- Enhanced treatment technologies may be required
  - Phosphorus in treated effluent through flocculation and coagulation is about 30 ug/L compared with conventional BMPs which is about 60 ug/L
- Manage snowmelt to maximize evapotranspiration
- Manage runoff volumes and/or instream measures to reduce stream erosion