Nutrient Criteria – Missouri Reservoirs – DRAFT Feb. 8, 2007

Assumptions/Approach

1. In keeping with the "regional" scope of this effort, separate criteria will be developed for reservoirs in the Ozark Highlands, Ozark Border and the Plains sections of the state. Criteria for Big River lakes and reservoirs are not addressed in this document.

2. Criteria will be developed for phosphorus as the basis for water quality protection and improvement.

3. The proportion of original prairie cover and original forest cover (at the time of European settlement) is an appropriate metric of the physiographic characteristics of the Plains ecotone in Missouri. Prairie landscapes are inherently more fertile than forested landscapes, and reservoir built in former prairie soils will reflect this fertility. The pre-settlement prairie and forest data base was compiled by Jim Harlan (MU) from original state survey records.

Background statement

The USEPA's National Strategy for the Development of Regional Nutrient Criteria (Gibson *et al*. 2000) focuses on setting numeric criteria for causal variables such as phosphorus with the aim of achieving desired levels of the response variables algal chlorophyll and water transparency. The suggested approach to establishing criteria centers on the distribution of these variables in high-quality baseline reference lakes. This approach is best suited for landscapes with glacial lakes, where waterbodies with minimal anthropogenic influences may be numerous enough to allow for meaningful analysis. The majority of classified lentic systems in Missouri are reservoirs, built for uses such as flood control, drinking water sources or recreation. In order to meet these uses, most where built in developed landscapes during the last 50 years, often near populated areas. Relatively few Missouri reservoirs are located in landscapes that can be described as minimally impacted, especially in the Plains regions of the state where historic prairie land cover has been all but eradicated.

Water quality differs over a broad range among these artificial lakes but research has shown that nutrient concentrations are largely determined by non-point source inputs, morphology and hydrology (Jones *et al*. 2004). This cross-system response shown in reservoir nutrient concentrations is consistent with theory that underpins our understanding of eutrophication and lake management.

Among reservoirs in the Missouri Plains (n=90), long-term mean total phosphorus values vary from 14 to 189 µg/L. This wide range of water quality is directly related to the broad range of deterministic factors. Dam height of these reservoirs range from 20 to126 feet; flushing rate ranges from 0.1 to >6.0 times per year; and the proportion of the watershed that was prairie prior to European settlement (a measure of fertility within the watershed) ranges from 0 to 100%. About 15% (n=12) of these Plains water bodies support phosphorus values < 25 µg/L, which is generally accepted as the upper limit of mesotrophic conditions in temperate lakes. These mesotrophic impoundments are not truly representative of typical physiographic conditions in the Plains region and are not reference lakes of the type described in the USEPA's National Strategy for the Development of Regional Nutrient Criteria document (Gibson *et al*. 2000). The morphology, hydrology and original vegetation cover of these12 low-nutrient reservoirs contrasts sharply with features of most impoundments in the Missouri Plains and accounts for differences in nutrient content between the two groups. Using median values from these groups to illustrate differences – low nutrient impoundments are deeper (dam height 65.5 feet vs. 40.5 feet), have slower hydraulic flushing (0.3/year vs. 1.1/year) and are located in landscapes with less original prairie (~10% vs. 83%) than other reservoirs in the Missouri Plains. Simply put, the geographic setting of low-nutrient Plains reservoirs differs from other impoundments in the region; they are located in unique valley catchments on the margins of the original prairie and benefit from being deeper and having longer water residence than lakes constructed in valleys of the original prairie landscape. Each of these features favor low nutrient concentrations.

A suggested alternative to the "reference" approach involves setting criteria based on data collected from non-reference water bodies. EPA suggests using the 25th percentile of data (ordered from lowest to highest phosphorus concentrations) from a monitored population of lakes to approximate the criterion that would have been set had reference lakes been available. The wide range of deterministic factors (flushing rate, depth, pre-settlement land cover) that accounts for the broad g range of water quality in Plains reservoirs greatly reduces the utility of this approach. A reservoir on the upper end of the trophic gradient is nutrient rich because of a combination of high flushing, shallow depth, fertile watershed soils and watershed disturbances. While in-reservoir nutrient levels can be reduced by managing the disturbances, the other factors (which were set when the reservoirs was built) greatly limit the reservoir's ability to attain low nutrient status.

Proposed criteria for Plains reservoirs

Phosphorus criteria in Plains reservoirs will be the greater value of a threshold concentration of 25 µg/L or the product of (% old prairie/4) + (flushing rate x 16) + (570/dam height in feet).

This equation is the outcome of a multiple regression analysis using long-term data from 90 Plains reservoirs (MU data), and it accounts for 57% of cross-system variation in reservoir long-term phosphorus concentrations. Original prairie was used to represent the dominate vegetation type in the ecoregion prior to European settlement. This approach is consistent with the intent of a physiographic evaluation of potential/ambient conditions in setting nutrient criteria as prairie soils are considerably more fertile than forest soils. Research in Missouri (Jones et al. 2004) shows that phosphorus levels increase with hydraulic flushing rate and decline with reservoir depth. Our analysis of Plains reservoirs suggests that phosphorus levels increase by 25 µg/L across the range of historic prairie cover when all other factors are held constant (Fig. 1), increase by 90 µg/L across the ambient range of flushing rate values (Fig. 2), and increase by 35 µg/L across the observed range of reservoir depth (Fig. 3, expressed as 1/dam height). The arithmetic adjustments to old prairie, flushing rate and dam height in the proposed calculation for phosphorus criterion values for individual Plains reservoirs are taken from the slope coefficients in multiple regression analysis of the 90 Plains reservoirs in the MU data set. This format of the equation was selected for simplicity. The calculated product of this multi-part equation provides a reservoir-specific criterion for phosphorus based on unique characteristics of each water body in the Missouri Plains.

Among Plains reservoirs monitored for at least four years, 42 of 90 have long-term phosphorus values that comply with proposed criteria (Table 1). The difference between the long-term mean and calculated phosphorus criterion in non-compliant reservoirs was ≤ 10 µg/L in 46% of the cases (Table1), with 28% of non-compliant reservoirs differing from criteria by > 20 µg/L (ranging up to 88 µg/L above criteria).

Proposed criteria for Ozark reservoirs

Phosphorus criteria in Ozark reservoirs will be the greater value of a threshold concentration of 10 µg/L or the product of 5µg/L + (740/dam height in feet).

Analyses of the MU data set suggests lake depth is the primary determinant of cross-system variation in reservoir phosphorus values and that values in Ozark reservoirs increase by 25 µg/L across the observed range (Fig. 4). Neither old prairie nor flushing rate added to the explanatory power of this analysis, nor were other factors in the data set significant. Use of an arithmetic adjustment to reservoir dam height provides a reservoir-specific criterion for the majority of reservoirs in the Ozark Highlands. While the threshold concentration of 10 µg/L represents a realistic and protective nutrient concentration for the deepest Ozark reservoirs.

Among Ozark reservoirs 21 of 34 (62%) have long-term phosphorus values that comply with proposed criteria (Table 2). The difference between long-term mean phosphorus values and suggested criterion was ≤ 10 µg/L in 15% of Ozark reservoirs (Table 2), with the remaining reservoirs differing by as much as 38 µg/L.

Proposed criteria for Ozark Border reservoirs

Phosphorus criteria in Ozark Border reservoirs will be the greater value of a threshold concentration of 20 µg/L or the product of 15 µg/L + (740/dam height in feet).

The Ozark Border is a region of physiographic transition, having a blend of geology and topography that reflects both the Plains and Ozark regions. Variations in soils (associations and depth), bedrock geology, relief and pre-settlement land cover limit our ability to develop predictive models exclusively for this region. When Border reservoirs were included in the analysis preformed on Ozark reservoirs, they generally fit the pattern described by the formula 740/dam height (feet). They differed in that the majority (82%) of Border reservoirs had long-term phosphorus values above the calculated criteria. In order to address differences in geology and topography that would explain why Border reservoirs generally exceeded criteria, the intercept of the regression line was increased to 15 µg/L. This slight change in the formula allows water quality in Border reservoirs to reflect the ecotonal conditions.

Analysis indicates that 12 of 22 (55%) Border reservoirs have long-term phosphorus values that meet proposed criteria (Table 3). The ten remaining reservoirs exceed criteria by 1 to 36 µg/L.

Variation in the data

Not all individual samples from compliant reservoirs will be within the bounds of the proposed criteria. Review of MU data indicate that 23% of individual samples (395 of 1707) collected from compliant Plains reservoirs surpassed suggested criteria. Use of these individual values to gauge compliance would lead to a false-positive; a listing of the reservoir as being non-compliant when in reality the overall phosphorus level is below the criterion. Use of individual values can also lead to false-negatives; an assumption that the reservoir meets the criterion when the overall phosphorus level is actually higher than the criterion. In the data set for non-compliant Plains reservoirs, 31% (777 of 2514) of individual phosphorus measurements were below the criterion. Similar findings occurred when data from the Ozark and Border regions were reviewed. Aggregation of data to annual summer means did not greatly reduce the number of false-positive and false-negative measurement. Because of the inherent variability in water quality parameters, it is highly recommended that data be collected for at least four summers (≥4 samples per summer) before comparisons are made to calculated criteria. Data from fewer years would lead to a substantial number of both false-positive and false-negative errors as indicated in the above analysis (see also Knowlton and Jones 2006). Data collections from a four year span would not eliminate the risk of incorrectly assessing a reservoir's water quality relative to criterion, but it would greatly reduce the risk of making an error.

Nutrient criteria for fishing reservoirs

A large number of small to moderate size impoundments in the state have been constructed by Missouri Department of Conservation (MDC) to provide recreational fishery opportunities. These MDC reservoirs are located throughout the state and are managed for 'creel' returns and benefit from fertility. The MDC pond book states a Secchi between 1.5 - 2.5 feet is optimal for warm-water fish propagation. This transparency would correspond to a phosphorus range of 50 to100 µg/L. In some cases MDC fertilizes these lakes to promote productivity and fish growth. With this in mind, it is suggested that reservoirs built and managed specifically for fishing be allotted a higher phosphorus criterion, as a lower value would reduce productivity. For such lakes a relaxed phosphorus criterion is appropriate.
Possibly:
Plains Reservoirs – the larger of 75 µg/L or the calculated criterion;
Border Reservoirs - the larger of 60 µg/L or the calculated criterion;
Ozark Reservoirs – the larger of 50 µg/L or the calculated criterion.

The MU data set contains long-term information on 41 MDC owned reservoirs, and 22 of these were non-compliant based on regional criteria. Replacing criteria calculated using regional formulas with the relaxed criteria proposed above reduces non-compliant reservoirs from 22 to 7 (Table 4).

Table 1. Plains reservoirs with long-term phosphorus values (µg/L) and criterion calculated using the following formula: (% old prairie/4) + (flushing rate *16) + (570/dam height in feet).
*denotes reservoirs in which the threshold value of 25 µg/L is used as criterion

MU#	Lake Name	Mean Phosphorus	Calculated Criterion	Difference
62	Westmoreland	21	102	-81
53	Memphis City	75	119	-43
6	Lake St. Louis	63	96	-33
161	Bushwacker	28	59	-31
89	Truman	36	64	-28
77	Allaman	39	66	-26
183	Hazel Hill	49	72	-23
130	LaPlata	26	47	-22
189	Butler City	68	88	-21
61	Vandalia	58	77	-19
87	Brookfield	22	40	-18
55	Baring Country Club	27	44	-18
50	Spring	26	43	-17
211	Cameron #2	53	70	-16
120	Winnebago	44	58	-14
159	Harmony Mission	43	57	-14
94	Lamar City	70	83	-13
85	Marie*	14	25	-11
45	NehaiTonkeia*	14	25	-11
66	PrairieLee	50	61	-11
169	Gopher	94	104	-10
148	Blue Springs	35	45	-9
191	Indian Creek	23	32	-9
5	Lincoln*	16	25	-9
155	Weatherby Lake*	16	25	-9
68	Longview	32	41	-8
182	Fox Valley*	17	25	-8
162	Maple Leaf	40	47	-7
70	North Lake	93	99	-6
67	Lotawana	31	35	-4
181	Monzingo	30	34	-4
3	Bowling Green*	21	25	-4
133	Forest*	22	25	-3
54	Ella Ewing	78	81	-3
64	Odessa	38	41	-3
116	Jacomo	30	32	-2
56	Edina City	64	65	-1
179	Nodaway	42	43	-1
47	Moberly	49	49	-1
158	Amarugia Highlands	46	47	-1
80	Viking*	25	25	0
71	Waukomis*	25	25	0
65	Tapawingo	33	32	1
115	Hunnewell	42	40	2

Table 1. continued

113	Pape (Concordia)	67	65	2
131	Hazel Creek*	27	25	2
157	Holden City	40	37	3
145	Mark Twain	53	50	3
118	Raintree	51	47	4
83	Bethany*	29	25	4
185	Harrison County	56	52	4
129	LaBelle	60	55	5
91	Atkinson	69	64	5
69	Harrisonville	46	41	5
72	Smithville	34	28	6
114	Henry Sever	43	37	6
52	Thunderhead	44	37	6
60	Monroe City	77	70	6
137	Green City	71	65	7
180	Bilby Ranch	51	43	8
48	Long Branch	46	38	8
78	Hamilton City	55	47	8
86	New Milan	38	28	10
187	Belcher Branch*	35	25	10
84	Paho	50	39	10
132	Lancaster	70	59	11
7	Kraut Run (Busch #33)	96	85	11
74	Watkins Mill	40	28	12
57	Deer Ridge	40	26	13
49	Macon	51	37	14
90	Montrose	149	134	15
46	Thomas Hill	46	30	16
203	Willow Brook	75	58	17
81	Pony Express	64	47	17
73	Williams (Rocky Hollow)	68	50	18
119	Sterling Price	93	74	18
168	Nell	78	56	22
59	Shelbina	96	74	22
51	Unionville	93	70	23
164	Elmwood	52	28	24
117	Little Dixie	55	30	25
121	Higginsville	83	54	28
150	Blind Pony	75	46	29
167	Cottontail	149	119	30
82	Maysville	162	120	42
88	Marceline (new)	83	38	45
63	Spring Fork	134	89	46
212	Grindstone	141	65	76
140	Cameron #1	178	94	84
163	King	189	101	88

Table 2. Ozark reservoirs with long-term phosphorus values (μg/L) and criterion calculated using the following formula: 5 μg/L + (740/dam height in feet).
*denotes reservoirs in which the threshold value of 10 μg/L is used as criterion

MU#	Lake Name	Mean Phosphorus	Calculated Criterion	Difference
106	Roby	14	54	-40
20	Monsanto	9	30	-20
102	Noblet	11	30	-19
109	Loggers	9	27	-18
186	Bismark	20	36	-16
105	Austin	19	32	-13
35	Miller Community	20	32	-13
108	Turner (Shawnee)	17	28	-12
107	Ziske (Macs)	26	36	-10
112	Shayne	6	15	-9
40	Sunnen	12	20	-9
33	Fourche Creek	9	17	-9
32	Ripley	24	32	-9
17	Carmel	8	16	-8
146	Crane	14	21	-7
18	Capri	6	13	-7
19	Marseilles	9	16	-6
39	Council Bluff	7	12	-4
104	Sims Valley	24	27	-3
37	Lower Taum Sauk	12	15	-3
98	Table Rock*	9	10	-1
96	Fellows	13	12	0
93	Stockton*	11	10	2
99	Taneycomo	21	18	3
36	Clearwater*	13	10	4
110	Little Prairie	27	20	6
95	McDaniel	32	20	11
111	Indian Hills	32	20	12
149	Lake of the Ozarks*	23	10	13
30	Wappapello	36	23	13
11	Peaceful Valley	30	17	14
92	Pomme de Terre*	24	10	14
38	Killarney	57	31	26
97	Springfield	59	21	38

Table 3. Ozark Border reservoirs with long-term phosphorus values (µg/L) and criterion calculated using the following formula: 15 µg/L + (740/dam height in feet).
*denotes reservoirs in which the threshold value of 20 µg/L is used as criterion

MU#	Lake Name	Mean Phosphorus	Calculated Criterion	Difference
41	Rocky Fork	21	64	-43
16	Timberline	8	24	-17
15	Wauwanoka	13	27	-15
144	Pinewoods	33	45	-12
2	Pinnacle	19	30	-11
42	Tri City	43	54	-11
27	Boutin	21	31	-10
10	Northwoods	21	30	-9
21	Goose Creek*	12	20	-8
26	Bella Vista	23	30	-8
14	Tishomingo	20	26	-6
43	D.C.Rogers	29	31	-2
44	Fayette	38	37	1
22	Ann	39	31	9
29	Tywappity	47	36	11
24	Fredricktown City	59	46	13
23	Wanda Lee	46	31	15
28	Girardeau	51	34	17
1	Glover	58	37	20
13	Binder	51	30	21
184	Manito	87	57	30
25	Perry Co. Community	67	31	36

Table 4. Reservoirs owned and managed by Missouri Department of Conservation for fishing, with "relaxed" criterion replacing calculated criterion values.

MU#	Lake Name	Region	Mean Phosphorus	Criterion	Difference
182	Fox Valley	Plains	17	75	-58
191	Indian Creek	Plains	23	75	-52
161	Bushwacker	Plains	28	75	-47
187	Belcher Branch	Plains	35	75	-40
57	Deer Ridge	Plains	40	75	-35
162	Maple Leaf	Plains	40	75	-35
179	Nodaway	Plains	42	75	-33
115	Hunnewell	Plains	42	75	-33
159	Harmony Mission	Plains	43	75	-32
114	Henry Sever	Plains	43	75	-32
158	Amarugia Highlands	Plains	46	75	-29
183	Hazel Hill	Plains	49	75	-26
84	Paho	Plains	50	75	-25
180	Bilby Ranch	Plains	51	75	-24
117	Little Dixie	Plains	55	75	-20
61	Vandalia	Plains	58	75	-17
81	Pony Express	Plains	64	75	-11
169	Gopher	Plains	94	104	-10
91	Atkinson	Plains	69	75	-6
203	Willow Brook	Plains	75	75	0
150	Blind Pony	Plains	75	75	0
168	Nell	Plains	78	75	3
54	Ella Ewing	Plains	78	75	3
119	Sterling Price	Plains	93	75	18
7	Kraut Run (Busch #33)	Plains	96	75	21
167	Cottontail	Plains	149	119	30
163	King	Plains	189	101	88
108	Turner (Shawnee)	Ozarks	17	50	-33
105	Austin	Ozarks	19	50	-31
35	Miller Community	Ozarks	20	50	-30
186	Bismark	Ozarks	20	50	-30
104	Sims Valley	Ozarks	24	50	-26
107	Ziske (Macs)	Ozarks	26	50	-24
110	Little Prairie	Ozarks	27	50	-23
41	Rocky Fork	Border	21	64	-43
42	Tri City	Border	43	60	-17
29	Tywappity	Border	47	60	-13
28	Girardeau	Border	51	60	-9
13	Binder	Border	51	60	-9
25	Perry Co. Community	Border	67	60	7
184	Manito	Border	87	60	27

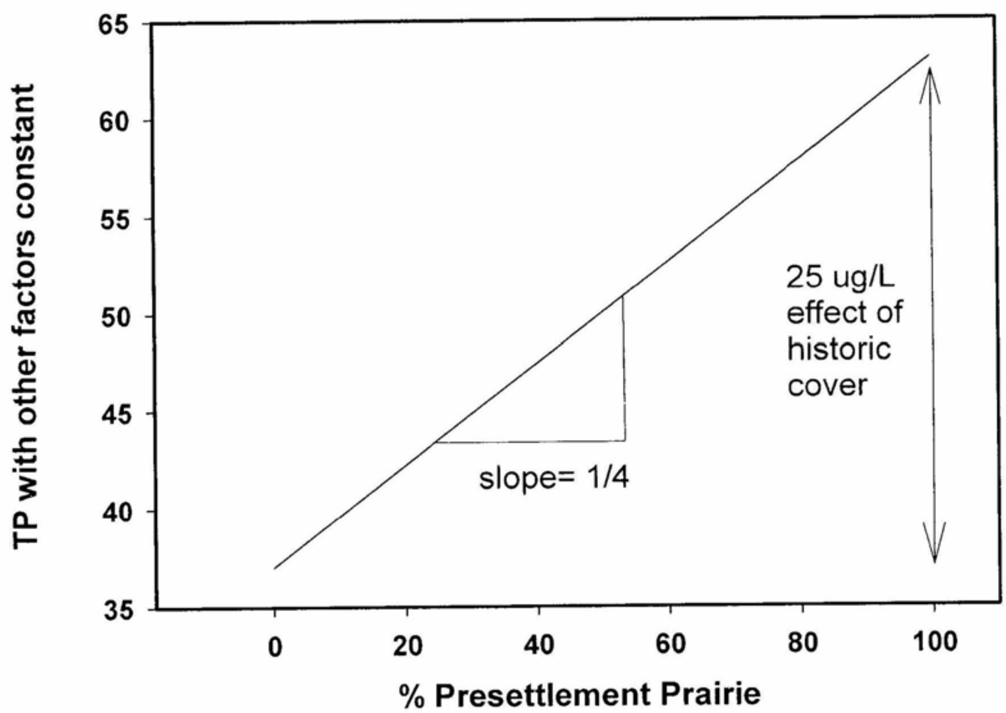

Figure 1. The influence of pre-settlement prairie on phosphorus concentrations in Plains reservoirs when all other factors are held constant.

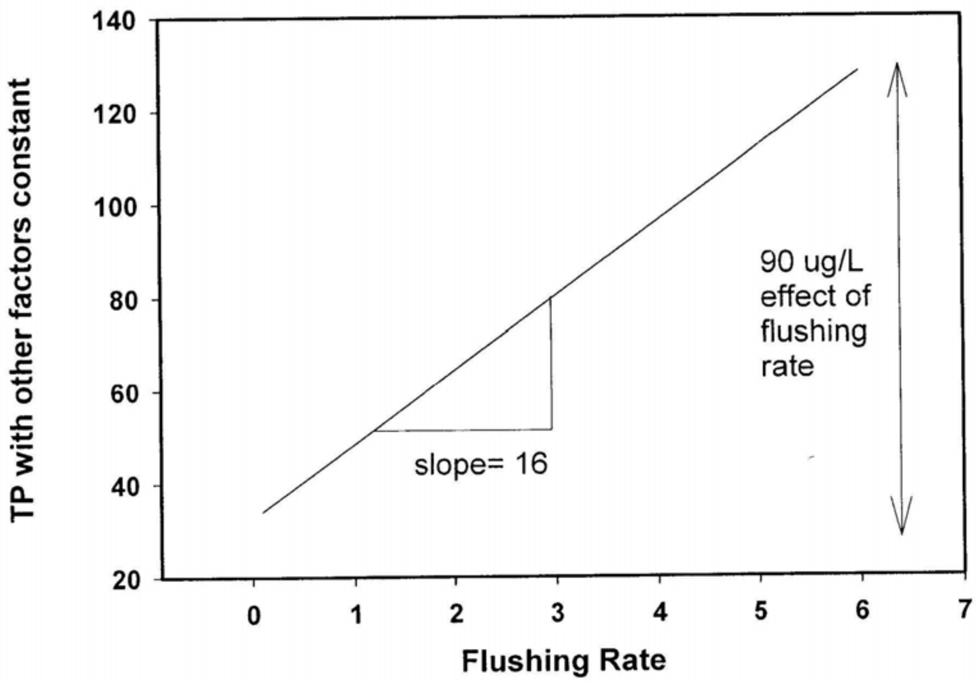

Figure 2. The influence of flushing rate on phosphorus concentrations in Plains reservoirs when all other factors are held constant.

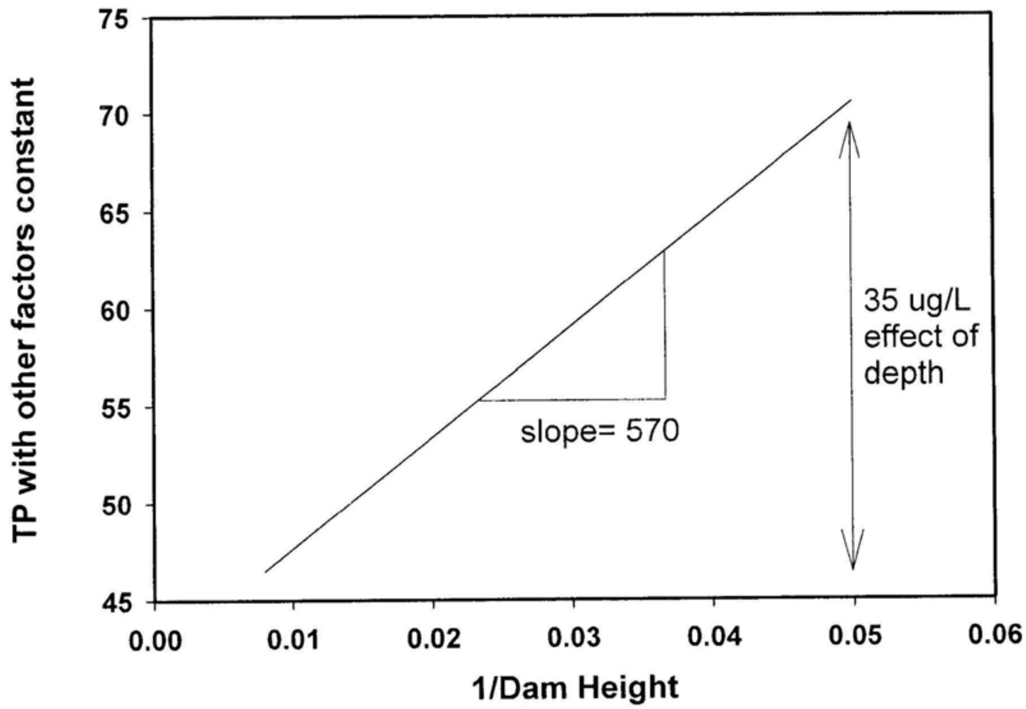

Figure 3. The influence of dam height on phosphorus concentrations in Plains reservoirs when all other factors are held constant.

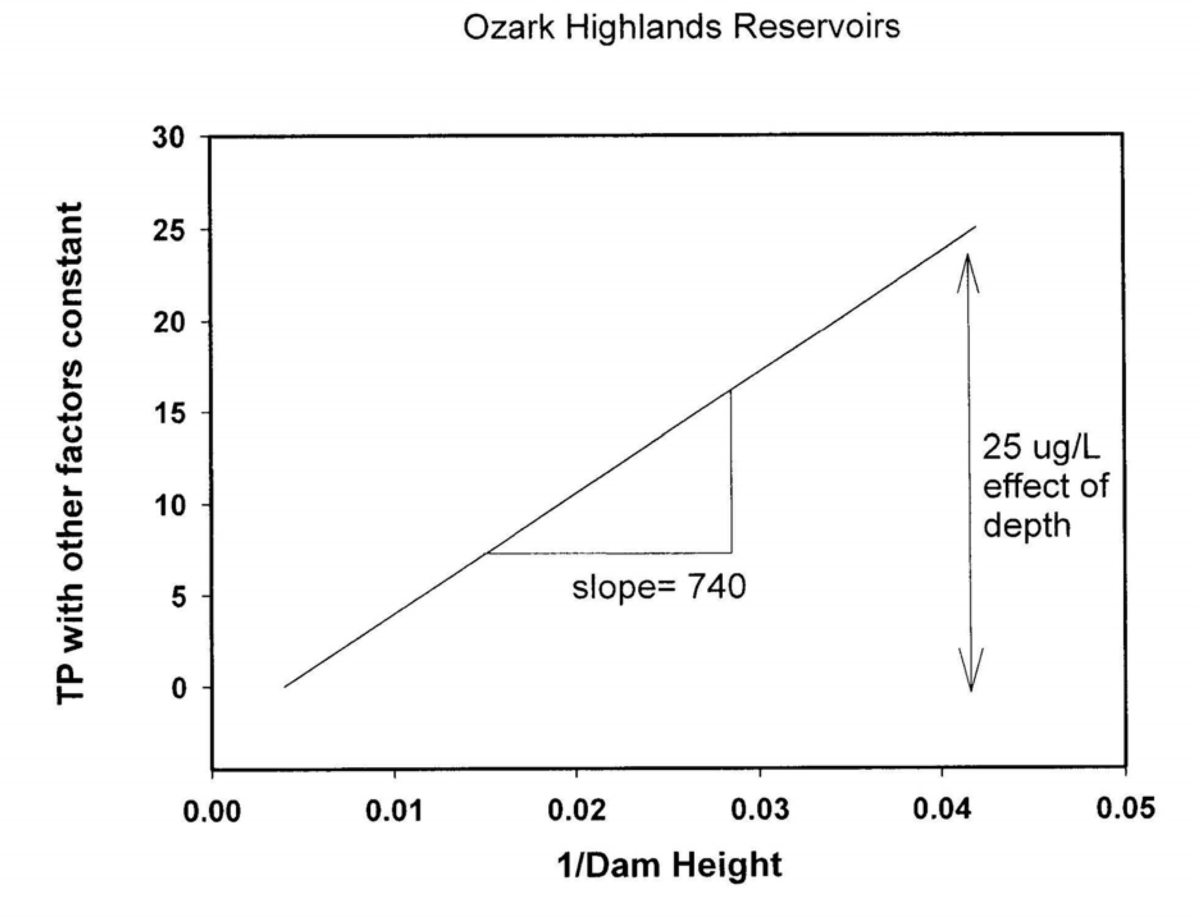

Figure 4. The influence of dam height on phosphorus concentrations in Ozark reservoirs when all other factors are held constant.