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Spokane County Department of Utilities
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Attention: Ben Brattebo
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Subject: Technical Memorandum
Groundwater Loading Analyses – Orthophosphate
Bi-State Nonpoint Source Phosphorus Study
File No. 0188-135-01

INTRODUCTION

In a previous technical memorandum entitled *Preliminary Groundwater Loading Analyses, Bi-State Nonpoint Source Phosphorus Study* and dated August 4, 2009 (GeoEngineers 2009a), GeoEngineers presented results of preliminary analyses estimating the loading of **total phosphorus** to the Spokane River and its tributaries from groundwater. Groundwater loads to the Spokane River and its tributaries were calculated for reaches where sufficient existing data were available. That simplified analysis was performed by comparing baseflow contributions associated with gaining stream segments with total phosphorus concentrations in groundwater adjacent to those reaches. Total phosphorus concentrations include particulate phosphorus which might not be mobile in groundwater and, as such, use of total phosphorus data could overestimate phosphorus loads.

The groundwater loading analyses summarized in this memorandum were performed as a component of Task 3 of the Phase 1 Supplement of the Bi-State Nonpoint Source Phosphorus Study (NPS Study). The above-described analyses were replicated using representative **orthophosphate**, rather than total phosphorus, concentrations. Note that laboratory data previously reported for “soluble reactive phosphorus” was assumed equivalent to orthophosphate for the purposes of the analyses described herein.

In response to input from the Washington State Department of Ecology regarding our draft submittal, this final technical memorandum incorporates the following primary modifications:

- In addition to orthophosphate loading within gaining stream segments, orthophosphate losses within identified losing stream segments were estimated.

- Orthophosphate concentrations in surface water within losing stream segments were estimated by calculation of median, rather than average, concentrations. Orthophosphate concentrations in groundwater within gaining stream segments continued to be estimated by calculation of average concentrations, for consistency with GeoEngineers (2009a).

STREAMFLOW GAINS AND LOSSES

Existing information previously was compiled and reviewed regarding the locations and quantities of streamflow gains and losses within the Spokane River and its tributaries and was summarized in GeoEngineers (2009a). That information primarily is limited to the Spokane and Little Spokane Rivers and their interaction with the Spokane Valley-Rathdrum Prairie (SVRP) Aquifer (Hsieh et.al 2007), as well as Hangman Creek and its interaction with the Hangman Valley Aquifer (SCCD 2005).

The compilation of streamflow gains and losses presented by GeoEngineers (2009a) is summarized in Table 1. Gauging stations and streamflow measurement sites used to define gaining and losing river segments are presented in Gauging Stations and Streamflow Measurement Sites, Figure 1.

TABLE 1. SPOKANE RIVER WATERSHED GAINS AND LOSSES

Spokane River Segment	Streamflow gain (+) or loss (-) (cfs)
Near Lake Coeur d'Alene to Near Post Falls	-291
Near Post Falls to Near Otis Orchards	-191
Near Otis Orchards to Greenacres	-110
Greenacres to Flora Road	-14
Flora Road to Centennial Trail Bridge	360
Centennial Trail Bridge to Below Green Street	233
Below Green Street to USGS (Spokane)	-112
USGS (Spokane) To T.J. Meenach Bridge	88.5
T.J. Meenach Bridge To Rifle Club Road	38
Rifle Club Road to Below Nine Mile Dam	141
Total	142.5
Little Spokane River Segment	Streamflow gain (+) or loss (-) (cfs)
Upstream of USGS (at Dartford)	Not Available
USGS (at Dartford) to Waikiki Rd	168
Waikiki Rd to USGS (near Dartford)	80
USGS (near Dartford) to near confluence	-16 to -31
Total	217 to 232

Hangman Creek River Segment	Streamflow gain (+) or loss (-) (cfs)
Upstream of River Mile 21.0	Various Minor Gaining and Losing Segments
River Mile 21.0 to Duncan	-1.0
Duncan to Downstream of Hangman Creek Golf Course	-0.7
Downstream of Hangman Creek Golf Course to USGS gage on Hangman Creek	16.5
Total	14.8

ORTHOPHOSPHATE CONCENTRATIONS

General

In order to estimate the amount of phosphorus exchanged between surface and groundwater within identified gaining and losing reaches within the Spokane River watershed, representative phosphorus concentrations for the exchanged water must be estimated. Representative phosphorus concentrations were developed by evaluation of groundwater data adjacent to gaining reaches and surface water data within and/or adjacent to losing reaches, as described below.

Gaining Reaches

Methodology

Orthophosphate concentrations in groundwater throughout the study area were compiled as a component of Phase 1 of the Bi-State Nonpoint Source Phosphorus Study and entered into the project database (GeoEngineers 2009b). Most groundwater orthophosphate data compiled for this study are associated with the portion of the SVRP Aquifer located within Washington; sampling locations outside of the boundaries of the SVRP Aquifer are limited in number.

Orthophosphate concentrations used to calculate the daily load introduced to gaining river segments were estimated using techniques consistent with those used to estimate the total phosphorus concentrations described by GeoEngineers (2009a). For individual wells situated adjacent to respective gaining stream segments, orthophosphate concentrations in groundwater samples were averaged over the well's period of record. The resulting well concentrations within each gaining segment were then averaged to derive representative orthophosphate concentrations.

The locations of individual wells used in our analysis are presented in Well Locations, Figure 2. The Spokane River and Little Spokane River were segmented for this analysis according to the August 26 to 31, 2005 seepage run described by Hsieh et.al (2007). The portion of Hangman Creek situated below the confluence with Marshall Creek also was examined.

For comparison, both orthophosphate and total phosphorus (in italics) concentrations are presented in tables within this report section. However, the text describes only the orthophosphate data. For a discussion of reported total phosphorus concentrations, refer to GeoEngineers (2009a). For context, note



that a target range in total phosphorus concentration of 10 to 50 micrograms per liter ($\mu\text{g/L}$) previously has been proposed for point source discharges to the Spokane River as a part of the Total Maximum Daily Load (TMDL) process.

Spokane River

FLORA ROAD TO CENTENNIAL TRAIL BRIDGE

Ten wells sampled between the period from 1999 to 2009 were included in our analysis of average orthophosphate concentrations in groundwater discharging to the Spokane River segment between Flora Road and the Centennial Trail Bridge and are listed in Table 2. These wells range in distance from the Spokane River from about 164 feet (Well 1092) to 8,864 feet (Well 1352). The number of samples collected from these wells ranges from 1 (Well 3483) to 44 (Well 1330). The average groundwater orthophosphate concentrations in individual wells ranges from about 3.5 $\mu\text{g/L}$ (Well 1333) to 61.5 $\mu\text{g/L}$ (Well 1324). The average phosphorus concentration in samples collected from Well 1324, and to a lesser extent Well 1352, are anomalously high, however no technical basis has been identified to exclude these data at this time. The average orthophosphate concentration in groundwater discharging to this river segment is estimated to be about 15.3 $\mu\text{g/L}$, or about 35 percent of the equivalent average for total phosphorus.

TABLE 2. RELEVANT GROUNDWATER WELL INFORMATION FOR WELLS BETWEEN FLORA ROAD AND CENTENNIAL TRAIL BRIDGE

Well ID	Average Orthophosphate Concentration ($\mu\text{g/L}$)	Average Total Phosphorus Concentration¹ ($\mu\text{g/L}$)	Number of Samples Collected²	Sample Depth^{2,3} (feet)	Sampling Years²	Distance from River (feet)
1091	5.8	13.6	4	NA	1999	387
1092	6.5	17.3	4	NA	1999	164
1093	6.8	17.8	4	NA	1999	266
1324	61.5	254.8	12	109.5-110.5	2006-2008	748
1329	10.5	20.5	33	25-38.5	2000-2008	422
1330	7.5	19.4	44	24-38	2000-2009	214
1331	9.8	14.5	35	47.5-59.2	2000-2008	277
1333	3.5	20.4	10	NA	2006-2008	7,388
1352	49.5	87.0	11	111.5-120	2006-2008	8,864
3483	7.0	39.3	1	NA	2007	7,370
Average⁴	15.3	44.2				

Notes:

1. Total phosphorus concentrations were described in GeoEngineers (2009a) and provided herein for comparison with equivalent orthophosphate analyses.
 2. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).
 3. Sample depth refers to ground surface.
 4. Overall reach averages were calculated over the entire dataset (rather than averaging individual well averages) to give each data point equal weight.
- NA = Not available.

CENTENNIAL TRAIL BRIDGE TO BELOW GREENE STREET

Nineteen wells sampled between the period from 2000 to 2009 were included in our analysis of average orthophosphate concentrations in groundwater discharging to the Spokane River segment between Centennial Trail Bridge to below Greene Street and are listed in Table 3. These wells range in distance from the Spokane River from about 556 feet (Well 1361) to 9,804 feet (Well 1365). The number of samples collected from these wells ranges from 3 (Wells 1366 and 1367) to 44 (Well 1314). The average groundwater orthophosphate concentrations in individual wells ranges from about 5.0 µg/L (Well 1327) to 53.2 µg/L (Well 1365). The average orthophosphate concentration in groundwater discharging to this river segment is estimated to be about 12.3 µg/L, or about 50 percent of the equivalent average for total phosphorus.

TABLE 3. RELEVANT GROUNDWATER WELL INFORMATION FOR WELLS BETWEEN CENTENNIAL TRAIL BRIDGE AND BELOW GREENE STREET

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration ¹ (µg/L)	Number of Samples Collected ²	Sample Depth ^{2,3} (feet)	Sampling Years ²	Distance from River (feet)
3476	20.3	5.7	6	NA	2000-2004	2463
2360	NA	40.0	NA	NA	NA	5195-9132
2340	NA	36.1	NA	NA	NA	4853
2339	NA	40.0	NA	NA	NA	4816
2338	NA	23.9	NA	NA	NA	4851
1367	25.2	19.9	3	NA	2001-2006	1533
1366	41.4	8.8	3	NA	2001-2004	3356
1365	53.2	58.7	9	50-59.5	2000-2002	9804
1361	6.9	10.7	5	59	2001	556
1328	9.8	15.0	26	86-95.5	2002-2008	2175
1327	5.0	12.7	35	NA	2000-2008	5751
1326	15.2	16.1	17	NA	2001-2008	3253
1325	14.2	14.7	27	NA	2001-2008	1328
1322	16.4	19.8	35	42-55	2000-2008	8939
1320	11.1	18.3	36	90-91	2000-2008	8293
1319	13.1	14.9	36	47-54.5	2000-2008	8293
1318	10.1	18.5	38	61.5-72	2000-2008	6017
1317	17.0	25.7	20	NA	2000-2008	4165
1316	20.7	23.7	39	64.5-69	2000-2008	1967
1315	7.7	12.2	37	90-106	2000-2008	2472
1314	7.4	12.2	44	62.8-70	2000-2009	2477
1313	6.8	8.2	36	34-42	2003-2009	990
1309	7.3	11.7	32	182-182.5	2000-2008	5776
Average⁴	12.3	24.7				

Notes:

1. Total phosphorus concentrations were described in GeoEngineers (2009a) and provided herein for comparison with equivalent orthophosphate analyses.
2. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).
3. Sample depth refers to ground surface.
4. Overall reach averages were calculated over the entire dataset (rather than averaging individual well averages) to give each data point equal weight.

NA = Not available.

SPOKANE (SPOKANE RIVER USGS GAUGING STATION) TO T.J. MEENACH BRIDGE

Three wells sampled between the period from 2000 to 2009 were included in our analysis of average orthophosphate concentrations in groundwater discharging to the Spokane River segment between the Spokane River USGS gauging station and the T.J. Meenach Bridge and are listed in Table 4. These wells range in distance from the Spokane River from about 264 feet (Well 1307) to 4,179 feet (Well 1310). The number of samples collected from these wells ranges from 12 (Well 1307) to 35 (Wells 1308 and 1310). The average groundwater orthophosphate concentrations in individual wells ranges from about 4.0 µg/L (Well 1307) to 11.6 µg/L (Well 1308). The average orthophosphate concentration in groundwater discharging to this river segment is estimated to be about 8.6 µg/L, or about 60 percent of the equivalent average for total phosphorus.

TABLE 4. RELEVANT GROUNDWATER WELL INFORMATION FOR WELLS FROM SPOKANE TO T.J. MEENACH BRIDGE

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration ¹ (µg/L)	Number of Samples Collected ²	Sample Depth ^{2,3} (feet)	Sampling Years ²	Distance from River (feet)
1307	4.0	19.0	12	NA	2007-2009	264
1308	11.6	15.9	35	NA	2000-2008	3,070
1310	7.1	12.6	35	148-149	2000-2008	4,179
Average⁴	8.6	14.4				

Notes:

1. Total phosphorus concentrations were described in GeoEngineers (2009a) and provided herein for comparison with equivalent orthophosphate analyses.
2. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).
3. Sample depth refers to ground surface.
4. Overall reach averages were calculated over the entire dataset (rather than averaging individual well averages) to give each data point equal weight.

NA = Not available.

T.J. MEENACH BRIDGE TO RIFLE CLUB ROAD

One well (Well 3474) sampled in 2007 was included in our analysis of average orthophosphate concentrations in groundwater discharging to the Spokane River segment between T.J. Meenach Bridge and Rifle Club Road and is detailed in Table 5. Well 3474 is located about 620 feet from the Spokane

River. One sample was collected from Well 3474. The orthophosphate concentration in this sample was 6.0 µg/L, about 24 percent of the equivalent total phosphorus concentration (25.0 µg/L).

TABLE 5. RELEVANT GROUNDWATER WELL INFORMATION FOR WELLS FROM T.J. MEENACH BRIDGE TO RIFLE CLUB ROAD

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration ¹ (µg/L)	Number of Samples Collected ²	Sample Depth ^{2,3} (feet)	Sampling Years ²	Distance from River (feet)
3474	6.0	25.0	1	104	2007	620

Notes:

1. Total phosphorus concentrations were described in GeoEngineers (2009a) and provided herein for comparison with equivalent orthophosphate analyses.
2. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).
3. Sample depth refers to ground surface.

NA = Not available.

RIFLE CLUB ROAD TO BELOW NINE MILE DAM

No total phosphorus concentration data are available for groundwater contributing to the gaining reach of the Spokane River between Rifle Club Road to below Nine Mile Dam (approximately 140 cfs gain). An orthophosphate concentration of 4.8 µg/L was applied to this segment of the river and was approximated using a linear regression comparing orthophosphate concentration to river kilometer between the USGS gauging station at Spokane and Rifle Club Road.

Little Spokane River

USGS GAUGING STATION AT DARTFORD TO WAIKIKI ROAD

Two wells sampled between the period from 2001 to 2008 were included in our analysis of average orthophosphate concentrations in groundwater discharging to the Little Spokane River segment between the USGS gauging station at Dartford and Waikiki Road and are listed in Table 6. These wells range in distance from the Little Spokane River from about 554 feet (Well 3488) to 11,539 feet (Well 1347). The number of samples collected from these wells ranges from 11 (Well 3488) to 35 (Well 1347). The average groundwater orthophosphate concentrations in these two wells ranges from about 3.2 µg/L (Well 3488) to 3.9 µg/L (Well 1347). The average orthophosphate concentration in groundwater discharging to this river segment is estimated to be about 3.7 µg/L, or about 27 percent of the equivalent average for total phosphorus.

TABLE 6. RELEVANT GROUNDWATER WELL INFORMATION FOR WELLS BETWEEN THE USGS GAUGING STATION AT DARTFORD AND WAIKIKI ROAD

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration ¹ (µg/L)	Number of Samples Collected ²	Sample Depth ^{2,3} (feet)	Sampling Years ²	Distance from River (feet)
1347	3.9	12.9	35	NA	2000-2008	11,539
3488	3.2	22.0	11	NA	2007-2009	554
Average⁴	3.7	13.7				

Notes:

1. Total phosphorus concentrations were described in GeoEngineers (2009a) and provided herein for comparison with equivalent orthophosphate analyses.
2. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).
3. Sample depth refers to ground surface.
4. Overall reach averages were calculated over the entire dataset (rather than averaging individual well averages) to give each data point equal weight.

NA = Not available.

WAIKIKI ROAD TO USGS GAUGING STATION NEAR DARTFORD

Two wells sampled between the period from 2000 to 2009 were included in our analysis of average orthophosphate concentrations in groundwater discharging to the Little Spokane River segment between Waikiki Road and the USGS gauging station near Dartford and are listed in Table 7. These wells range in distance from the Little Spokane River from about 869 feet (Well 1345) to 946 feet (Well 3462). The number of samples collected from these wells ranges from 12 (Well 3462) to 38 (Well 1345). The average groundwater orthophosphate concentrations in these two wells ranges from about 4.7 µg/L (Well 3462) to 7.6 µg/L (Well 1345). The average orthophosphate concentration in groundwater discharging to this river segment is estimated to be about 6.9 µg/L, or about 49 percent of the equivalent average for total phosphorus.



TABLE 7. RELEVANT GROUNDWATER WELL INFORMATION FOR WELLS BETWEEN WAIKIKI ROAD AND THE USGS GAUGING STATION NEAR DARTFORD

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration ¹ (µg/L)	Number of Samples Collected ²	Sample Depth ^{2,3} (feet)	Sampling Years ²	Distance from River (feet)
1345	7.6	14.5	38	NA	2000-2008	869
3462	4.7	5.0	12	NA	2007-2009	946
Average⁴	6.9	14.0				

Notes:

1. Total phosphorus concentrations were described in GeoEngineers (2009a) and provided herein for comparison with equivalent orthophosphate analyses.
2. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).
3. Sample depth refers to ground surface.
4. Overall reach averages were calculated over the entire dataset (rather than averaging individual well averages) to give each data point equal weight.

NA = Not available.

Hangman (Latah) Creek

Three wells sampled between the period from 1990 and 1991 were included in our analysis of average orthophosphate concentrations in groundwater discharging to the Hangman Creek and are listed in Table 8. These wells range in distance from Hangman Creek from about 950 feet (Well 2107) to 11,700 feet (Well 2113). A range in sampling depth of 35 to 37.25 feet was reported for Well 2113, no other sampling depths were reported. The number of samples collected from these wells ranges from 2 (Well 2099) to 8 (Wells 2107 and 2113). The average groundwater orthophosphate concentrations in individual wells ranged from about 20.5 µg/L (Well 2099) to 153.6 µg/L (Wells 2107 and 2113). The average orthophosphate concentration in groundwater discharging to this river segment is estimated to be about 138.8 µg/L, or about 198 percent of the equivalent average for total phosphorus. Orthophosphate concentrations should not be higher than total phosphorus and, for these wells, average concentrations were likely skewed by the larger dataset available for orthophosphate relative to total phosphorus.

Note that these wells are situated significantly upgradient of the gaining stream segment evaluated during our loading analysis, but represent, in our opinion, the most technically-defensible total phosphorus estimates available with the current data set.

TABLE 8. RELEVANT GROUNDWATER WELL INFORMATION FOR WELLS IN THE HANGMAN CREEK SUBBASIN

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration ¹ (µg/L)	Number of Samples Collected ²	Sample Depth ^{2,3} (feet)	Sampling Years ²	Distance from Creek (feet)
2107	153.6	70	8	NA	1991-2004	950
2099	20.5	10	2	NA	1991	2,050

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration ¹ (µg/L)	Number of Samples Collected ²	Sample Depth ^{2,3} (feet)	Sampling Years ²	Distance from Creek (feet)
2113	153.6	130	8	35-37.25	1991-2004	11,700
Average⁴	138.8	70				

Notes:

1. Total phosphorus concentrations were described in GeoEngineers (2009a) and provided herein for comparison with equivalent orthophosphate analyses.
 2. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).
 3. Sample depth refers to ground surface.
 4. Overall reach averages were calculated over the entire dataset (rather than averaging individual well averages) to give each data point equal weight.
- NA = Not available.

Losing Reaches

Methodology

Representative orthophosphate concentrations in surface water within losing reaches were developed by examination of surface water data contained within the project database (GeoEngineers 2009b). The following methodology was used to develop surface water concentration estimates:

- Representative surface water sampling locations were selected.
 - § If a losing reach contained a single surface water sampling location, data from that location alone were examined.
 - § If a losing reach contained multiple surface water sampling locations, data from each of the locations were incorporated.
 - § If a losing reach contained no surface water sampling locations, data from one or more representative surface water sampling locations in close proximity to the losing reach were examined.
- Because the gaining reach analysis is based on seepage run data collected during July and August low flow periods, the project database was queried for data associated with only those months.
- The median of the resulting orthophosphate dataset was used as the representative concentration for each respective losing reach and subsequent phosphorus transport calculations.

Spokane River

NEAR LAKE COEUR D'ALENE TO NEAR POST FALLS

Five sampling locations were included in our analysis of orthophosphate concentrations in surface water between the near Lake Coeur d'Alene to near Post Falls gauging stations. These sampling locations are listed in Table 9. The number of samples collected during July and August from these sampling locations

ranges from 3 (Sampling Locations 2074, 2075, and 2078) to 17 (Sampling Location 510). The median orthophosphate concentration at individual locations ranges from about 4 µg/L (Sampling Location 510) to 30 µg/L (Sampling Location 2074). The median orthophosphate concentration in surface water samples collected from this river segment is 10 µg/L.

TABLE 9. RELEVANT SURFACE WATER INFORMATION BETWEEN NEAR LAKE COEUR D'ALENE AND NEAR POST FALLS

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
510	4	17	1973, 1989, 1992, 1996-2003	Yes
2071	6	11	1980, 2003-2005	Yes
2074	30	3	1980	Yes
2075	10	3	1980	Yes
2078	10	3	1980	Yes
Median²	10			

Notes:

1. Samples collected only during the months of July and August were included in the analysis.
2. Overall reach median was calculated over the entire dataset (rather than providing the median of individual well medians) to give each data point equal statistical weight.

NEAR POST FALLS TO NEAR OTIS ORCHARDS

Seven sampling locations were included in our analysis of orthophosphate concentrations in surface water between Post Falls to near Otis Orchards gauging stations. These sampling locations are listed in Table 10. The number of samples collected during July and August from these sampling locations ranges from 1 (Sampling Location 3590) to 53 (Sampling Location 1141). The median orthophosphate concentration at individual locations ranges from about 1 µg/L (Sampling Location 3590) to 10 µg/L (Sampling Location 2081). The median orthophosphate concentration in surface water samples collected from this river segment is 6 µg/L.

TABLE 10. RELEVANT SURFACE WATER INFORMATION BETWEEN NEAR POST FALLS AND NEAR OTIS ORCHARDS

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
511	2	2	1999	Yes
1131	5	3	1999-2000	Yes
1141	5.1	53	1971, 1973, 1977, 1991-2007	Yes
2081	10	50	1989-2003, 2007	Yes
2082	5.5	6	2003, 2008	Yes
2083	3	4	1999	Yes

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
3590	1	1	1992	Yes
Median²	6			

Notes:

1. Samples collected only during the months of July and August were included in the analysis.
2. Overall reach median was calculated over the entire dataset (rather than providing the median of individual well medians) to give each data point equal statistical weight.

NEAR OTIS ORCHARDS TO GREENACRES

Three sampling locations were included in our analysis of orthophosphate concentrations in surface water between Otis Orchards to Greenacres gauging stations. These sampling locations are listed in Table 11. The number of samples collected during July and August from these sampling locations ranges from 2 (Sampling Location 1114) to 18 (Sampling Location 3). The median orthophosphate concentration at individual locations ranges from about 6.75 µg/L (Sampling Location 1114) to 8.5 µg/L (Sampling Location 1130). The median orthophosphate concentration in surface water samples collected from this river segment is 8 µg/L.

TABLE 11. RELEVANT SURFACE WATER INFORMATION BETWEEN NEAR OTIS ORCHARDS AND GREENACRES

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
3	10	18	1980-1981	Yes
1114	10	2	2007	Yes
1130	3.9	4	1999-2000	Yes
Median²	10			

Notes:

1. Samples collected only during the months of July and August were included in the analysis.
2. Overall reach median was calculated over the entire dataset (rather than providing the median of individual well medians) to give each data point equal statistical weight.

GREENACRES TO FLORA ROAD

No surface water sampling locations with July or August orthophosphate data and situated between the Greenacres to Flora Road gauging stations are contained in the project database. Two representative sampling locations (1114 and 1130), both located about 3,000 feet upstream of the reach, were selected for evaluation. Data from these sampling locations are summarized in Table 12. A total of six samples were collected from these sampling locations during July and August with a median orthophosphate concentration of 8.5 µg/L.



TABLE 12. RELEVANT SURFACE WATER INFORMATION BETWEEN GREENACRES AND FLORA ROAD

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
1114	6.75	2	2007	No
1130	8.5	4	1999-2000	No
Median²	8.5			

Notes:

¹ Samples collected only during the months of July and August were included in the analysis.² Overall reach median was calculated over the entire dataset (rather than providing the median of individual well medians) to give each data point equal weight.**BELOW GREENE STREET TO USGS (SPOKANE)**

Three sampling locations were included in our analysis of orthophosphate concentrations in surface water between the Greene Street to USGS (Spokane) gauging stations. These sampling locations are listed in Table 13. The number of samples collected during July and August from these sampling locations ranges from 2 (Sampling Locations 517 and 1112) to 8 (Sampling Location 1066). The median orthophosphate concentration at individual locations ranges from about 3.9 µg/L (Sampling Location 1112) to 10 µg/L (Sampling Locations 517 and 1066). The median orthophosphate concentration in surface water samples collected from this river segment is 10 µg/L.

TABLE 13. RELEVANT SURFACE WATER INFORMATION BETWEEN NEAR OTIS ORCHARDS TO GREENACRES

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
517	10	2	1999	Yes
1066	10	8	1971, 1973	Yes
1112	3.9	2	2007	Yes
Median²	10			

Notes:

1. Samples collected only during the months of July and August were included in the analysis.

2. Overall reach median was calculated over the entire dataset (rather than providing the median of individual well medians) to give each data point equal statistical weight.

Little Spokane River**USGS (NEAR DARTFORD) TO NEAR CONFLUENCE**

Four sampling locations were included in our analysis of orthophosphate concentrations in surface water between the USGS station (near Dartford) to the gauging station near the confluence. These sampling locations are listed in Table 14. The number of samples collected during July and August from these sampling locations ranges from 2 (Sampling Location 1493) to 67 (Sampling Location 1492). The median orthophosphate concentration at individual locations ranges from about 10 µg/L (Sampling

Locations 1492 and 3608) to 12.5 µg/L (Sampling Location 1493). The median orthophosphate concentration in surface water samples collected from this river segment is 10 µg/L.

TABLE 14. RELEVANT SURFACE WATER INFORMATION BETWEEN USGS (NEAR DARTFORD) AND NEAR CONFLUENCE

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
1166	10.35	12	1999-2001	Yes
1492	10	67	1971, 1973, 1977-1991, 1994-2007	Yes
1493	12.5	2	1999	Yes
3608	10	4	1991	Yes
Median²	10			

Notes:

1. Samples collected only during the months of July and August were included in the analysis.
2. Overall reach median was calculated over the entire dataset (rather than providing the median of individual well medians) to give each data point equal statistical weight.

Hangman (Latah) Creek

RIVER MILE 21.0 TO DUNCAN

One sampling location was included in our analysis of orthophosphate concentrations in surface water between the River Mile 21.0 to Duncan gauging stations. This sampling location is listed in Table 15. Four samples were collected during July and August from this sampling location and the median orthophosphate concentrations is 62 µg/L.

TABLE 15. RELEVANT SURFACE WATER INFORMATION BETWEEN RIVER MILE 21.0 AND DUNCAN

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
3530	62	4	1991	Yes

Notes:

1. Samples collected only during the months of July and August were included in the analysis.

DUNCAN TO DOWNSTREAM OF HANGMAN CREEK GOLF COURSE

No surface water sampling locations with July or August orthophosphate data and situated between the Duncan to downstream of Hangman Creek Golf Course gauging stations are contained in the project database. A representative sampling location (No. 3532), situated about 350 feet upstream of the reach, was selected for evaluation. Data from this sampling location are summarized in Table 16. A total of four samples were collected from this sampling location during July and August with a median orthophosphate concentration of 94.5 µg/L.

TABLE 16. RELEVANT SURFACE WATER INFORMATION BETWEEN DUNCAN AND DOWNSTREAM OF HANGMAN CREEK GOLF COURSE

Sampling Location	Median Orthophosphate Concentration ¹ (µg/L)	Number of Samples Collected ¹	Sampling Years ¹	Within Losing Reach?
3532	94.5	4	1991	No

Notes:

1. Samples collected only during the months of July and August were included in the analysis.

PRELIMINARY LOADING ANALYSIS

General

Average loading of orthophosphate from groundwater to surface water was calculated for gaining stream segments as the product of streamflow gain and representative average groundwater orthophosphate concentrations. For comparison, both orthophosphate and total phosphorus (in italics) loading are presented in tables within this report section. However, the text describes only the orthophosphate data. For a discussion of estimated total phosphorus loading, refer to GeoEngineers (2009a). Orthophosphate losses with losing stream segments were calculated as the product of streamflow loss and representative median surface water orthophosphate concentrations.

Mainstem Spokane River

Based on the data and assumptions enumerated above, we estimate that approximately 54.1 lbs/day of orthophosphate enter the Mainstem Spokane River from groundwater between Lake Coeur d'Alene to below Nine Mile Dam. This represents about 40 percent of the estimated groundwater-based total phosphorus load for this river section.

Loads associated with specific gaining reaches are tabulated in Table 17. Orthophosphate loading generally decreases in the downstream direction, and ranges from about 1.2 lbs/day (T.J. Meenach Bridge to Rifle Club Road) to about 29.7 lbs/day (Flora Road to Centennial Trail Bridge).

Orthophosphate loss to groundwater within losing sections is estimated to be about 33.3 lbs/day within the mainstem Spokane River between Lake Coeur d'Alene to below Nine Mile Dam. Comparison of gains to losses yields a net loading of about 20.8 lbs/day.

TABLE 17. ORTHOPHOSPHATE EXCHANGE WITHIN THE MAINSTEM SPOKANE RIVER

Spokane River	Streamflow gain (+) or loss (-) (cfs)	Representative Orthophosphate Concentration (µg/L)	Orthophosphate Loading (+) or Loss (-) (lbs/day)	Total Phosphorus Loading (lbs/day)
Near Lake Coeur d'Alene to Near Post Falls	-291	10	-15.7	NA
Near Post Falls to Near Otis Orchards	-191	6	-6.2	NA
Near Otis Orchards to Greenacres	-110	8	-4.7	NA

Spokane River	Streamflow gain (+) or loss (-) (cfs)	Representative Orthophosphate Concentration (µg/L)	Orthophosphate Loading (+) or Loss (-) (lbs/day)	Total Phosphorus Loading (lbs/day)
Greenacres to Flora Road	-14	8.5	-0.6	NA
Flora Road to Centennial Trail Bridge	360	15.3	29.7	85.9
Centennial Trail Bridge to below Green Street	233	12.3	15.4	31.1
Below Green Street to USGS (Spokane)	-112	10	-6.0	NA
Spokane To T.J. Meenach Bridge	88.5	8.6	4.1	6.8
T.J. Meenach Bridge To Rifle Club Road	38	6.0	1.2	5.1
Rifle Club Road to below Nine Mile Dam	141	4.8 ¹	3.6	7.6
<i>Total Gain</i>			54.1	136.5
<i>Total Loss</i>			-33.3	NA
Net Loading			20.8	NA

Notes.

1. Estimated orthophosphate concentration based on linear regression of upgradient data.

NA = Not Available

Little Spokane River

Based on the data and assumptions enumerated above, we estimate that approximately 6.4 lbs/day of orthophosphate enter the Little Spokane River from groundwater between the USGS gauging station at Dartford and the confluence with the Spokane River (Table 18). This represents about 35 percent of the estimated groundwater-based total phosphorus load for this river section.

Orthophosphate loss to groundwater is estimated to be about 1.3 lbs/day within the Little Spokane River between the USGS gauging station at Dartford and the mouth. Comparison of gains to losses yields a net loading of 5.1 lbs/day.

TABLE 18. ORTHOPHOSPHATE EXCHANGE WITHIN THE LITTLE SPOKANE RIVER

Little Spokane River	Streamflow gain (+) or loss (-) (cfs)	Representative Orthophosphate Concentration (µg/L)	Orthophosphate Loading (+) or Loss (-) (lbs/day)	Total Phosphorus Loading (lbs/day)
at Dartford to Waikiki Rd	168	3.7	3.4	12.4
Waikiki Rd to near Dartford	80	6.9	3.0	6.0
USGS (near Dartford) to near confluence	-23.5	10	-1.3	NA
<i>Total Gain</i>			6.4	18.4
<i>Total Loss</i>			-1.3	NA
Net Loading			5.1	NA

Hangman (Latah) Creek

Baseflow to the segment of Hangman Creek located between the measurement location situated downstream of the Hangman Creek Golf Course and the USGS gauging station was reported by SCCD

(2005) at about 16.5 cfs during a seepage run conducted in July 2004. Results of our analysis suggest that orthophosphate loading to Hangman Creek from groundwater discharge within this stream segment is approximately 12.3 lbs/day during summer flow conditions, as presented in Table 19. This represents about 198 percent of the estimated groundwater-based total phosphorus load for this river section.

Orthophosphate loss to groundwater within losing sections is estimated to be about 0.7 lbs/day within Hangman Creek downstream of River Mile 21.0. Comparison of gains to losses yields a net loading of 11.6 lbs/day.

TABLE 19. ORTHOPHOSPHATE LOADING IN HANGMAN CREEK AS A FUNCTION OF STREAMFLOW GAIN

Hangman Creek	Streamflow gain (+) or loss (-) (cfs)	Representative Orthophosphate Concentration (µg/L)	Orthophosphate Loading (+) or Loss (-) (lbs/day)	Total Phosphorus Loading (lbs/day)
River Mile 21.0 to Duncan	-1.0	62	-0.3	NA
Duncan to Downstream of Hangman Creek Golf Course	-0.7	94.5	-0.4	NA
Downstream of Hangman Creek Golf Course to USGS Gage on Hangman Creek	16.5	138.8	12.3	6.2
<i>Total Gain</i>			12.3	6.2
<i>Total Loss</i>			-0.7	NA
Net Loading			11.6	NA

PRELIMINARY LOAD PRIORITIZATION

Groundwater-based orthophosphate loading to gaining reaches within the mainstem Spokane River, Little Spokane River and Hangman Creek is estimated to be about 72.8 lbs/day. This represents about 45 percent of the equivalent total phosphorus load estimated by GeoEngineers (2009a). Incorporating orthophosphate losses within identified losing reaches results in a net orthophosphate loading of about 37.6 lbs/day.

Based on the existing dataset and the analyses described above, we developed the following preliminary geographical prioritization with respect to orthophosphate loads entering study area surface water from groundwater, organized by receiving surface water body. In parentheses, we provide the percentage of the combined groundwater-based orthophosphate load estimated for the Spokane River, Little Spokane River, and Hangman Creek.

1. Spokane River (about 74 percent);
2. Hangman Creek (about 17 percent); and
3. Little Spokane River (about 9 percent).



Note that this does not include impacts from groundwater sources 1) upgradient of Lake Coeur d'Alene (which we believe could be significant but require further data and/or analysis to constrain) and 2) downgradient of Nine Mile Falls Dam (which have been evaluated as a component of this study and are summarized in GeoEngineers [2010]).

The above orthophosphate loading prioritization generally is consistent with the total phosphorus loading prioritization presented in GeoEngineers (2009a). The percentage of the watershed total phosphorus load attributed to the Spokane River (85 percent) is similar to that presented above. However, the total phosphorus load attributed to the Little Spokane River (11 percent) was greater than the load estimated for Hangman Creek (4 percent).

Orthophosphate loads entering the mainstem Spokane River from the SVRP Aquifer can be prioritized by gaining stream segment, as listed below as a function of total mainstem load percentage (in parentheses):

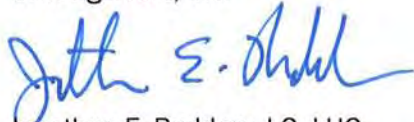
4. Flora Road to Centennial Trail Bridge (about 55 percent);
5. Centennial Trail Bridge to below Green Street (about 28 percent);
6. Spokane to T.J. Meenach Bridge (about 8 percent);
7. Rifle Club Road to below Nine Mile Dam (about 7 percent); and
8. T.J. Meenach Bridge to Rifle Club Road (about 2 percent).

This prioritization generally is consistent with the prioritization presented in GeoEngineers (2009a) for mainstem Spokane River total phosphorus loading. About 83 to 86 percent of the load occurs between Flora Road and Green Street for both orthophosphate and total phosphorus, with 14 to 17 percent of the load originating from downstream gaining reaches.

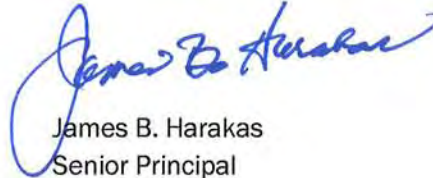


Preliminary loading estimates are summarized in Phosphorus Loading from Groundwater, Figure 3. Losses are summarized in Orthophosphate Losses from Surface Water, Figure 4.

Sincerely,
GeoEngineers, Inc.



Jonathan E. Rudders, LG, LHG
Senior Hydrogeologist



James B. Harakas
Senior Principal

JER:SHG:tlm
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List of Figures

Figure 1. Gauging Stations and Streamflow Measurement Sites

Figure 2. Well Locations

Figure 3. Phosphorus Loading from Groundwater

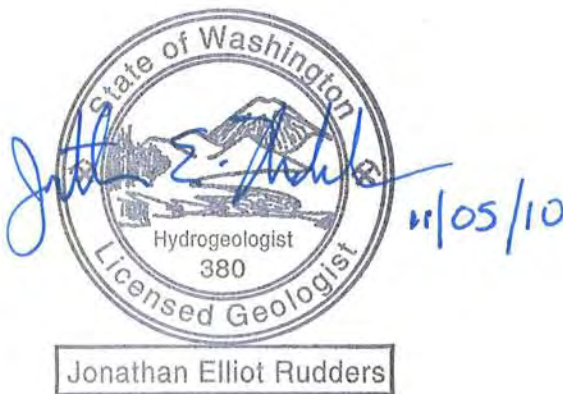
Figure 4. Orthophosphate Losses from Surface Water

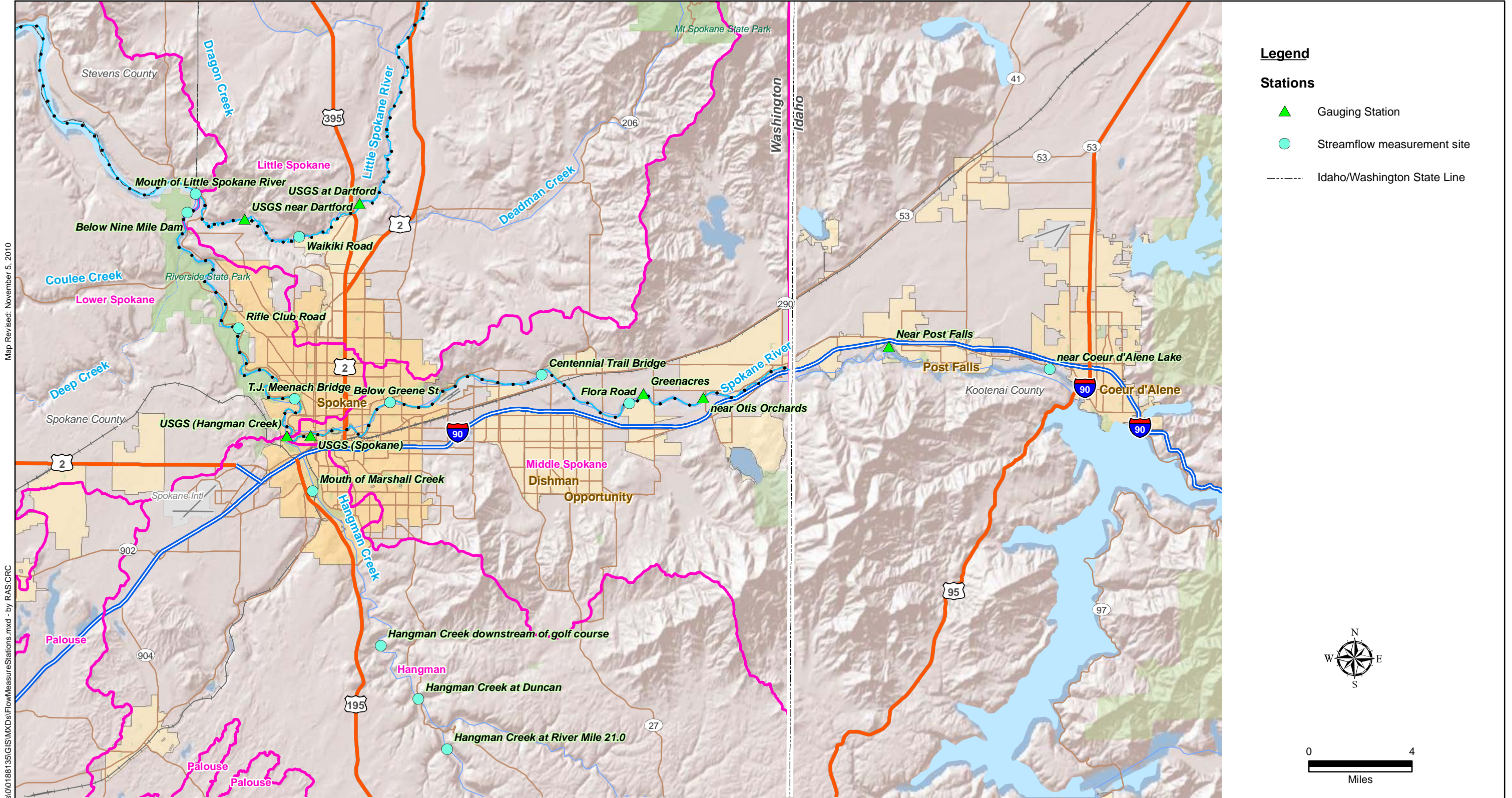
Appendices

Appendix A - References

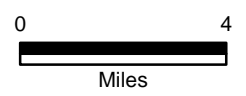
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- Legend**
- Stations**
- ▲ Gauging Station
 - Streamflow measurement site
 - Idaho/Washington State Line



Map Revised: November 5, 2010

Path: \\SPO\Projects\0188135\GIS\MXDs\FlowMeasureStations.mxd - by RAS:CRG

Office Location: SPO

Reference: Base features (hillshade, city boundaries, streets, rail) from ESRI.
Rivers and stations from Pacific Northwest Hyrdography

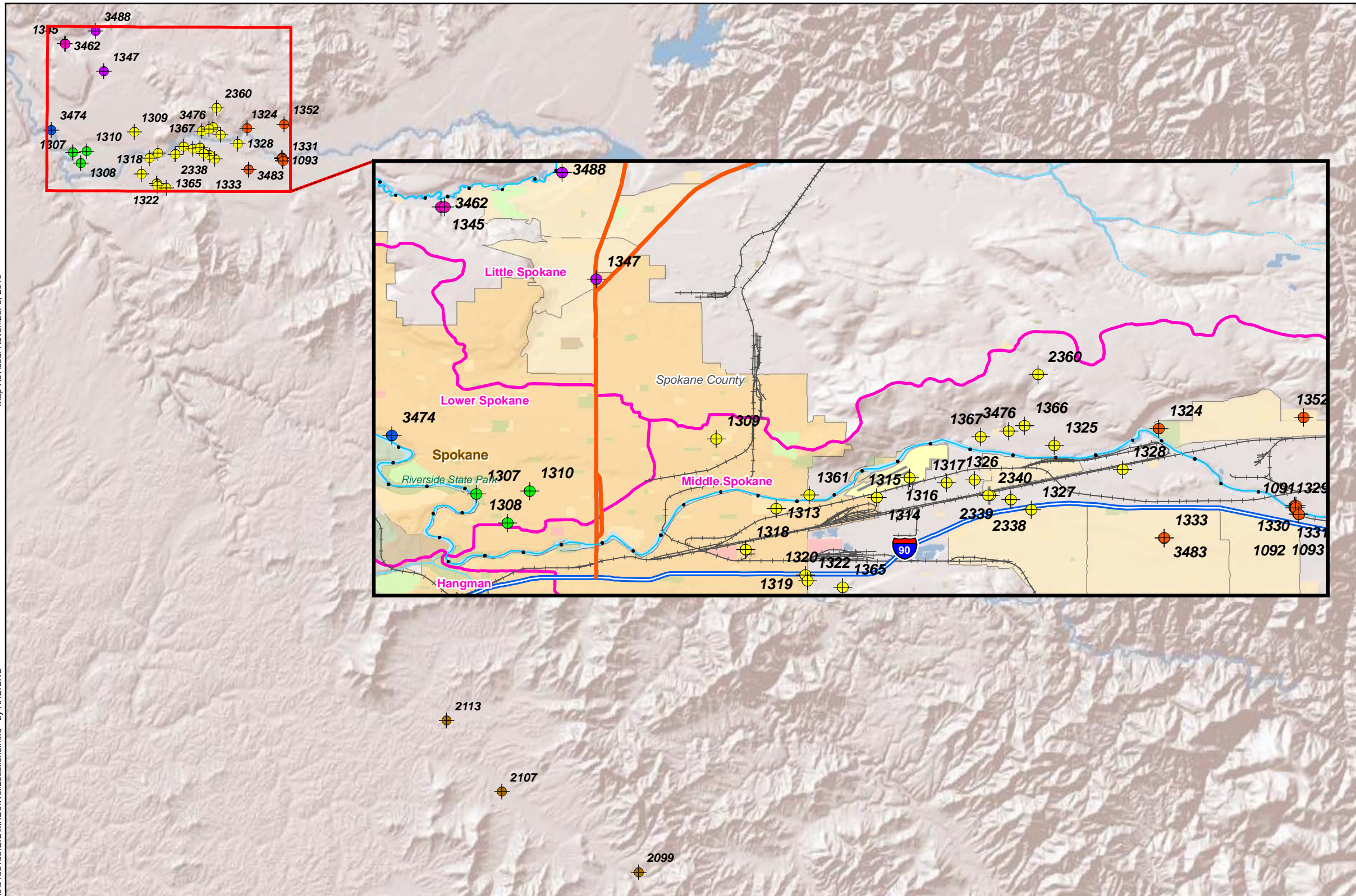
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Gauging Stations and Streamflow Measurement Sites	
Nonpoint Source Phosphorus Study Spokane County, Washington	
	Figure 1

Map Revised: November 5, 2010

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Office Location: SPO



Legend

Wells Used in Loading Analysis for Respective Stream Segments

Spokane River

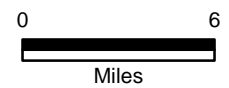
- Flora Road to Centennial Trail Bridge
- Centennial Trail Bridge to Below Greene St
- USGS gage (Spokane) to Meenach Bridge
- Meenach Bridge to Rifle Club Road

Little Spokane River

- USGS (at Dartford) to Waikiki Road
- Waikiki Road to USGS (near Dartford)

Hangman Creek

- Downstream of Hangman Creek Golf Course to USGS gage on Hangman Creek



Reference: Base features (hillshade, city boundaries, streets, rail) from ESRI. Rivers and stations from Pacific Northwest Hyrdography

Notes:

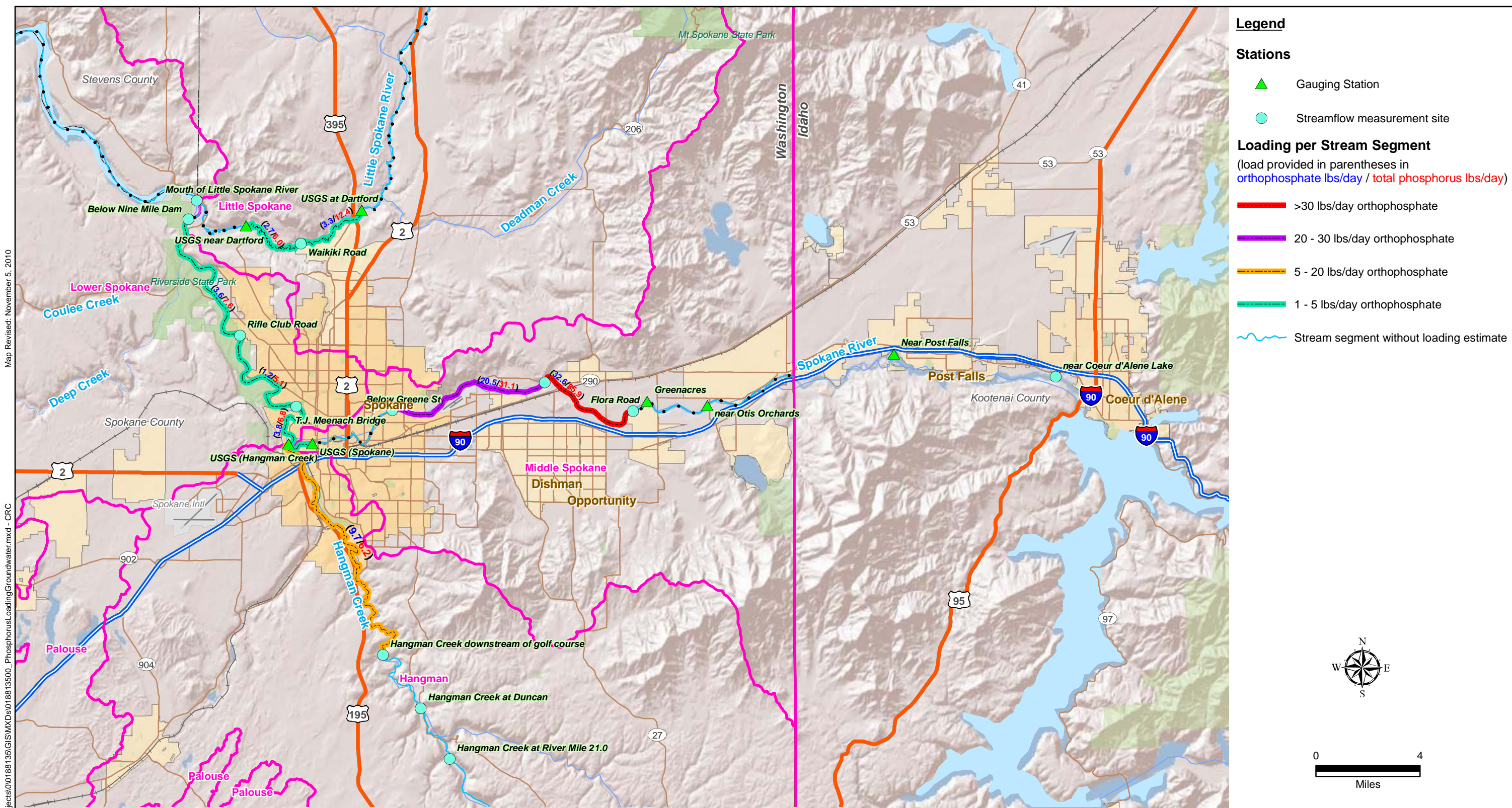
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Well Locations

Nonpoint Source Phosphorus Study
Spokane County, Washington



Figure 2



Legend

Stations

- ▲ Gauging Station
- Streamflow measurement site

Loading per Stream Segment
(load provided in parentheses in orthophosphate lbs/day / total phosphorus lbs/day)

- >30 lbs/day orthophosphate
- 20 - 30 lbs/day orthophosphate
- 5 - 20 lbs/day orthophosphate
- 1 - 5 lbs/day orthophosphate
- Stream segment without loading estimate

Map Revised: November 5, 2010

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Office Location: SPO

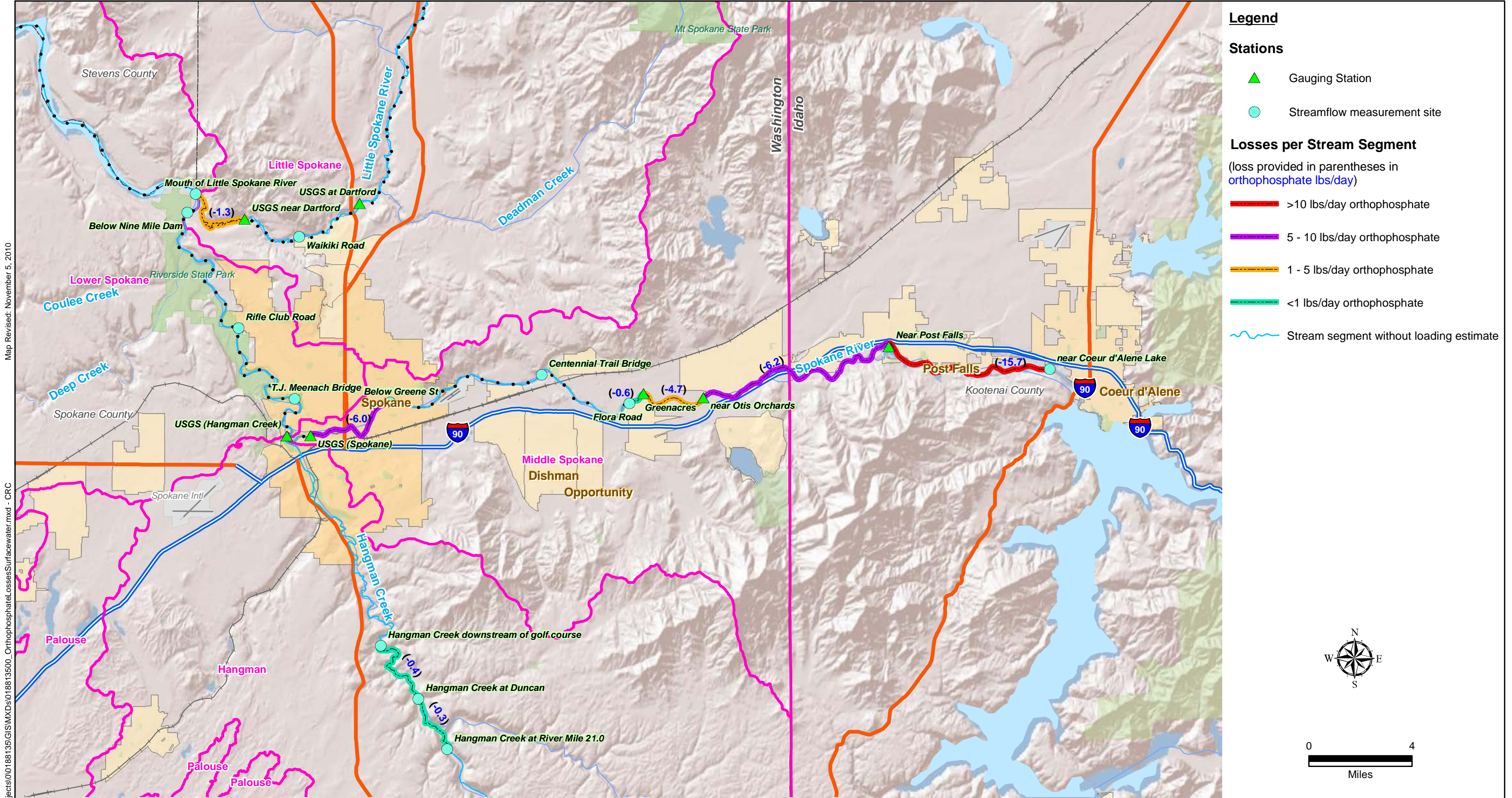
Reference: Base features (hillshade, city boundaries, streets, rail) from ESRI.
Rivers and stations from Pacific Northwest Hyrdography

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 3. lbs/day = pounds per day

**Phosphorus Loading
from Groundwater**

Nonpoint Source Phosphorus Study
Spokane County, Washington

GEOENGINEERS **Figure 3**



Map Revised: November 5, 2010

Path: \SPO\Projects\0188135\GIS\MXDs\018813500_OrthophosphateLossesSurfaceWater.mxd - CRC

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Reference: Base features (hillshade, city boundaries, streets, rail) from ESRI.
Rivers and stations from Pacific Northwest Hyrdography

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 3. lbs/day = pounds per day

Legend

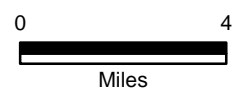
Stations

- ▲ Gauging Station
- Streamflow measurement site

Losses per Stream Segment

(loss provided in parentheses in orthophosphate lbs/day)

- >10 lbs/day orthophosphate
- 5 - 10 lbs/day orthophosphate
- 1 - 5 lbs/day orthophosphate
- <1 lbs/day orthophosphate
- ~ Stream segment without loading estimate



Orthophosphate Losses from Surface Water	
Nonpoint Source Phosphorus Study Spokane County, Washington	
	Figure 4



APPENDIX A
References

APPENDIX A REFERENCES

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