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February 2, 2010

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Attention Ben Brattebo
Water Resources Specialist

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. This simplified analysis was performed by comparing baseflow contributions associated with gaining stream segments with total phosphorus concentrations in groundwater adjacent to those reaches.

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 this analysis.

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). This information primarily is limited to the Spokane and Little Spokane Rivers and their interaction with the Spokane Valley-Rathdrum Prairie (SVRP) Aquifer, as well as Hangman Creek and its interaction with the Hangman Valley Aquifer.

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

TABLE 1. SPOKANE RIVER WATERSHED GAINS AND LOSSES

Spokane River Segment	Streamflow gain (+) or loss (-) (cfs)
Near Coeur d'Alene Lake to Flora Road	-606
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)
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 measurement site downstream of Hangman Creek Golf Course	Various Losing Segments
Downstream of Hangman Creek Golf Course to USGS gage on Hangman Creek	16.5

ORTHOPHOSPHATE CONCENTRATIONS

General

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 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 16.8 $\mu\text{g/L}$, or about 38 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 Concentration ($\mu\text{g/L}$)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	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	7388
1352	49.5	87.0	11	111.5-120	2006-2008	8864

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from River (feet)
3483	7.0	39.3	1	NA	2007	7370
Average	16.8	44.2				

Note.

1. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).

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 16.3 µg/L, or about 66 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 (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	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

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from River (feet)
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
Average	16.3	24.7				

Note.

1. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).

NA = Not available.

Spokane (Spokane River USGS gaging 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 gaging 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 7.6 µg/L, or about 53 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 (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from River (feet)
1307	4.0	19.0	12	NA	2007-2009	264
1308	11.6	15.9	35	NA	2000-2008	3070

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from River (feet)
1310	7.1	12.6	35	148-149	2000-2008	4179
Average	7.6	14.4				

Note.

1. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).

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 (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from River (feet)
3474	6.0	25.0	1	104	2007	620

Note.

1. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).

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 gaging station at Spokane and Rifle Club Road.

Little Spokane River

USGS gaging 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 gaging 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 3.6 µg/L, or about 26 percent of the equivalent average for total phosphorus.

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

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from River (feet)
1347	3.9	12.9	35	NA	2000-2008	11539
3488	3.2	22.0	11	NA	2007-2009	554
Average	3.6	13.7				

Note.

1. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).

NA = Not available.

Waikiki Road to USGS gaging 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 gaging 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 6.2 µg/L, or about 44 percent of the equivalent average for total phosphorus.

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

Well ID	Average Orthophosphate Concentration (µg/L)	Average Total Phosphorus Concentration (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from River (feet)
1345	7.6	14.5	38	NA	2000-2008	869
3462	4.7	5.0	12	NA	2007-2009	946
Average	6.2	14.0				

Note.

1. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).

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 109.2 µg/L, or about 156 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 (µg/L)	Number of Samples Collected ¹	Sample Depth ¹ (feet)	Sampling Years ¹	Distance from Creek (feet)
2107	153.6	70	8	NA	1991-2004	950
2099	20.5	10	2	NA	1991	2,050
2113	153.6	130	8	35-37.25	1991-2004	11,700
Average	109.2	70				

Note:

1. Number of samples, sample depth, and sampling years refer to orthophosphate concentrations. For the equivalent information for total phosphorus, refer to GeoEngineers (2009a).

NA = not available

PRELIMINARY LOADING ANALYSIS

General

Average loading of orthophosphate from groundwater to surface water was calculated for each gaining stream segment as the product of the streamflow gain and the assumed average groundwater orthophosphate concentration. 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).

Mainstem Spokane River

Based on the data and assumptions enumerated above, we estimate that approximately 61.6 lbs/day of orthophosphate enter the Mainstem Spokane River from groundwater between Flora Road to below Nine Mile Dam. This represents about 45 percent of the estimated groundwater-based total phosphorus load for this river section.

Loads associated with specific gaining reaches are tabulated in Table 9, phosphorus 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 32.6 lbs/day (Flora Road to Centennial Trail Bridge).

TABLE 9. ORTHOPHOSPHATE LOADED INTO THE SPOKANE RIVER ALONG SPECIFIC RIVER SEGMENTS.

Spokane River (River Kilometer) ¹	Streamflow gain (+) or loss (-) (cfs)	Average Orthophosphate Concentration (µg/L)	Orthophosphate Loading (lbs/day)	Total Phosphorus Loading (lbs/day)
Flora Road (148) to Centennial Trail Bridge (141)	360	16.8	32.6	85.9
Centennial Trail Bridge to below Green Street (130)	233	16.3	20.5	31.1
Spokane To T.J. Meenach Bridge (117.85)	88.5	7.6	3.6	6.8
T.J. Meenach Bridge To Rifle Club Road (108.5)	38	6.0	1.2	5.1
Rifle Club Road to below Nine Mile Dam (97.5)	141	4.8 ²	3.6	7.6
Total			61.6	136.5

Notes.

- 1 River kilometer in parentheses, 0 kilometer at confluence of Spokane River and Columbia River (Figure 1).
2. Assumed orthophosphate concentration based on linear regression of upgradient data.

Little Spokane River

Based on the data and assumptions enumerated above, we estimate that approximately 6.0 lbs/day of orthophosphate enter the Little Spokane River from groundwater between the USGS gaging station at Dartford and the confluence with the Little Spokane River (Table 10). This represents about 33 percent of the estimated groundwater-based total phosphorus load for this river section.

TABLE 10. ORTHOPHOSPHATE LOADED INTO THE LITTLE SPOKANE RIVER ALONG SPECIFIC RIVER SEGMENTS.

Little Spokane River	Streamflow gain (+) or loss (-) (cfs)	Average Orthophosphate Concentration (µg/L)	Orthophosphate Loading (lbs/day)	Total Phosphorus Loading (lbs/day)
at Dartford to Waikiki Rd	168	13.7	3.3	12.4

Little Spokane River	Streamflow gain (+) or loss (-) (cfs)	Average Orthophosphate Concentration (µg/L)	Orthophosphate Loading (lbs/day)	Total Phosphorus Loading (lbs/day)
Waikiki Rd to near Dartford	80	14.0	2.7	6.0
Total			6.0	18.4

Hangman (Latah) Creek

Significant contribution from baseflow to the segment of Hangman Creek located between the measurement location situated downstream of the Hangman Creek Golf Course and the USGS gaging station was reported by SCCD (2005) during a seepage run conducted during July 2004. Results of our analysis suggest that orthophosphate loading to Hangman Creek from groundwater discharge within this stream segment is approximately 9.7 lbs/day during summer flow conditions, as presented in Table 11. This represents about 156 percent of the estimated groundwater-based total phosphorus load for this river section.

TABLE 11. ORTHOPHOSPHATE LOADING IN HANGMAN CREEK AS A FUNCTION OF STREAMFLOW GAIN.

Hangman Creek	Streamflow gain (+) or loss (-) (cfs)	Average Orthophosphate Concentration (µg/L)	Orthophosphate Loading (lbs/day)	Total Phosphorus Loading (lbs/day)
Downstream of Hangman Creek Golf Course to USGS Gage on Hangman Creek	16.5	109.2	9.7	6.2

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 77.3 pounds per day. This represents about 48 percent of the equivalent total phosphorus load estimated by GeoEngineers (2009a).

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 80 percent);
2. Hangman Creek (about 12 percent); and
3. Little Spokane River (about 8 percent).

Note that this does not include impacts from groundwater sources 1) upgradient of Coeur d'Alene Lake (which we believe could be significant but require further data and/or analysis to constrain) and 2) downgradient of Nine Mile Falls Dam (which are currently being evaluated and will be submitted under separate cover).

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):

1. Flora Road to Centennial Trail Bridge (about 53 percent);
2. Centennial Trail Bridge to below Green Street (about 33 percent);
3. Rifle Club Road to below Nine Mile Dam (about 6 percent);
4. Spokane to T.J. Meenach Bridge (about 6 percent); and
5. 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. The prioritization order is identical. About 86 percent of the load occurs between Flora Road and Green Street for both orthophosphate and total phosphorus. However the loading percentage estimates for orthophosphate was about 10 percent lower and 10 percent higher than total phosphorus for the specific segments from Flora Road to Centennial Trail Bridge and from Centennial Trail Bridge to below Green Street, respectively.



Preliminary loading estimates are summarized in Figure 3.

Sincerely,
GeoEngineers, Inc.

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Senior Hydrogeologist

Sarah Hubbard Gray
Principal

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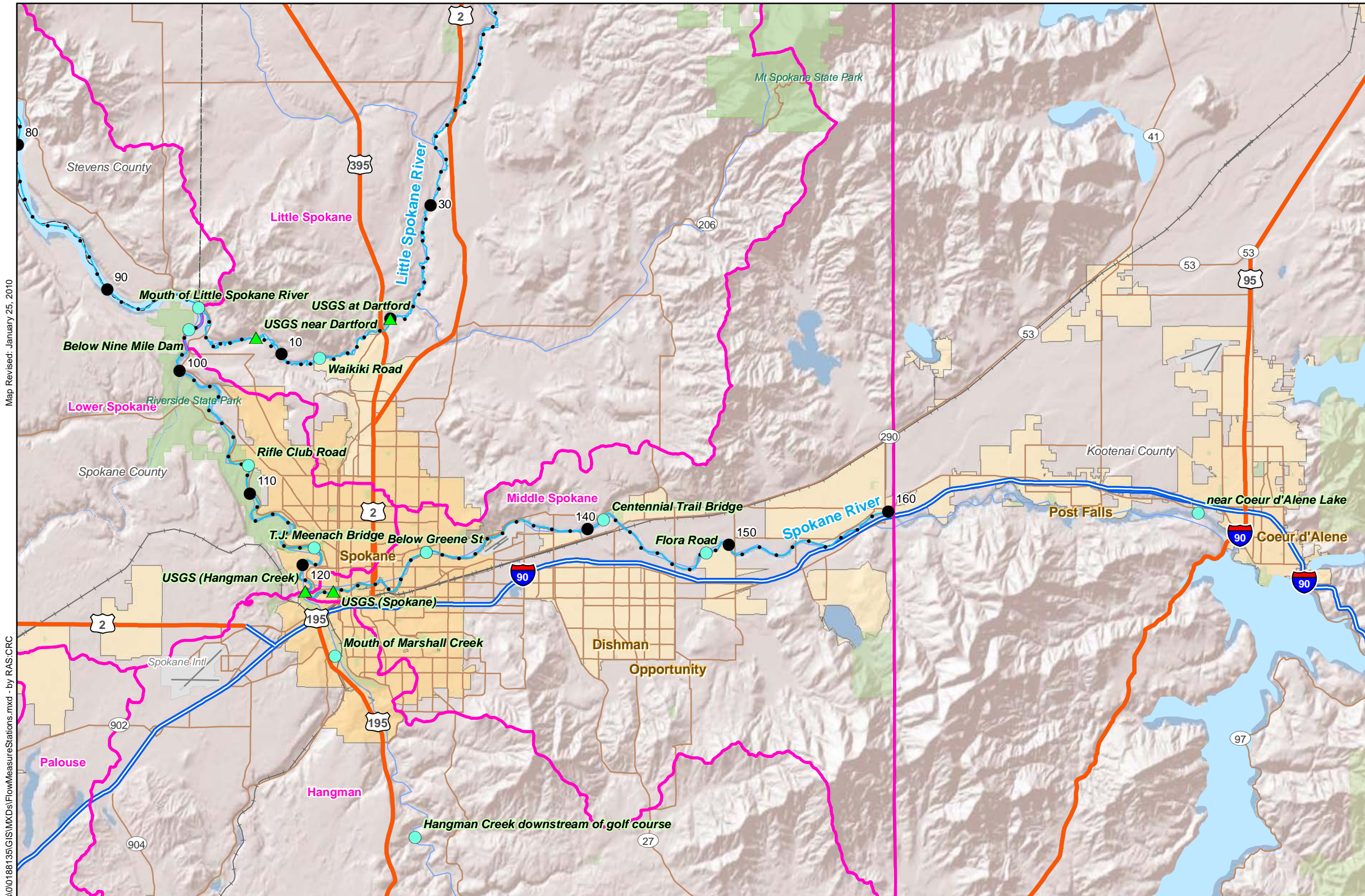
Appendices

Appendix A - References

Disclaimer: Any electronic form, facsimile or hard copy of the original document (email, text, table, and/or figure), if provided, and any attachments are only a copy of the original document. The original document is stored by GeoEngineers, Inc. and will serve as the official document of record.

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Legend

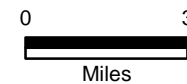
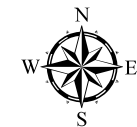
● River Kilometer

Stations

▲ Gaging Station

● Streamflow measurement site

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Map Revised: January 25, 2010

Path: \\SPO\Projects\00188135\GIS\MXDs\Flow\MeasureStations.mxd - by RAS:CRC

Office Location: SPO

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

Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. Future revisions of this figure may show different data.

Gaging Stations and Streamflow Measurement Sites

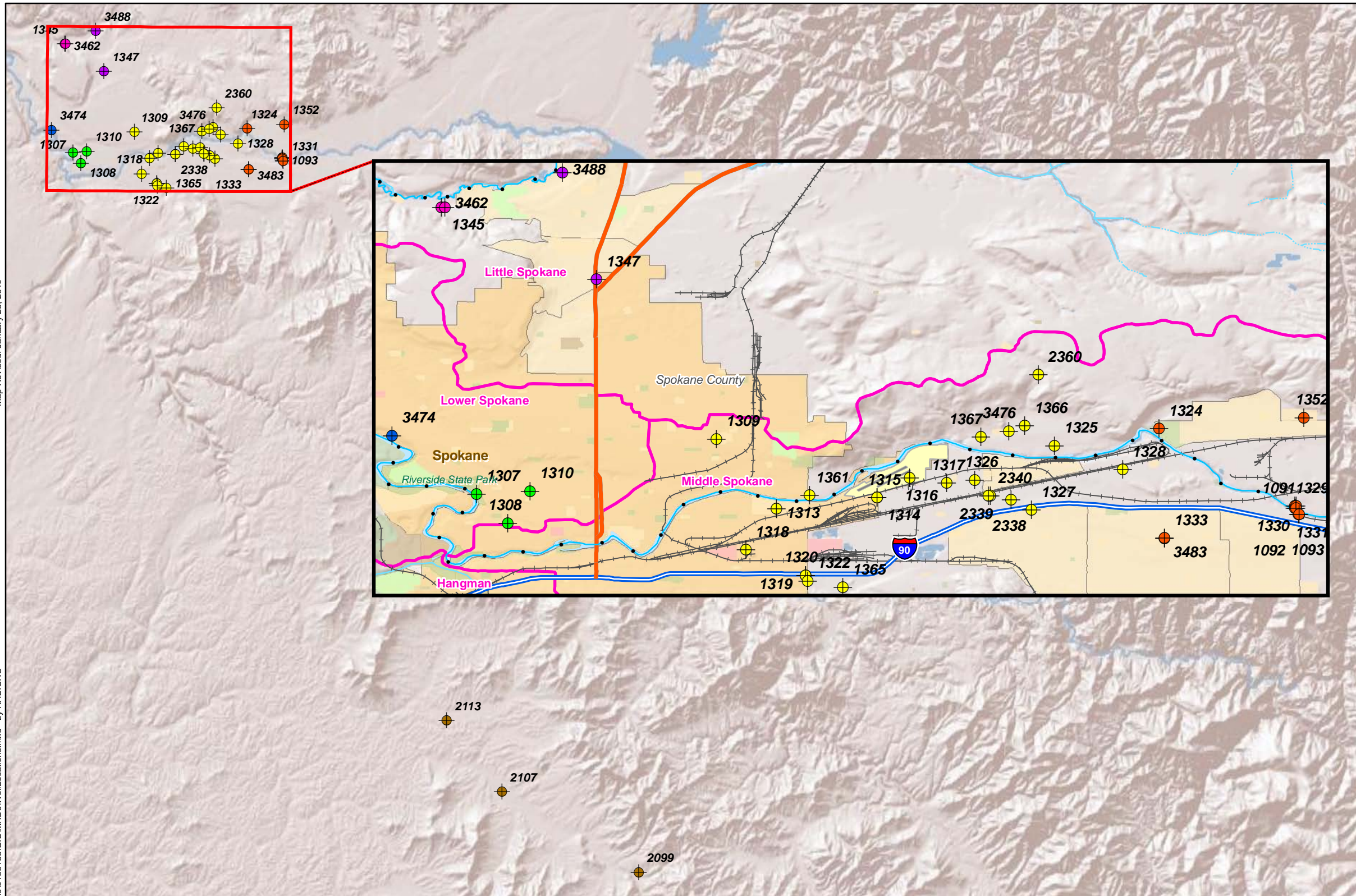
Nonpoint Source Phosphorus Study
Spokane County, Washington



Figure 1

Map Revised: January 25, 2010

Office Location: SPO Path: \\SPO\Projects\00188135\GIS\MXDs\WellLocations.mxd - by RAS,CRC



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

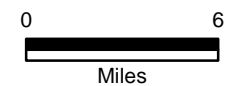
Little Spokane River

- 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

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

Notes:

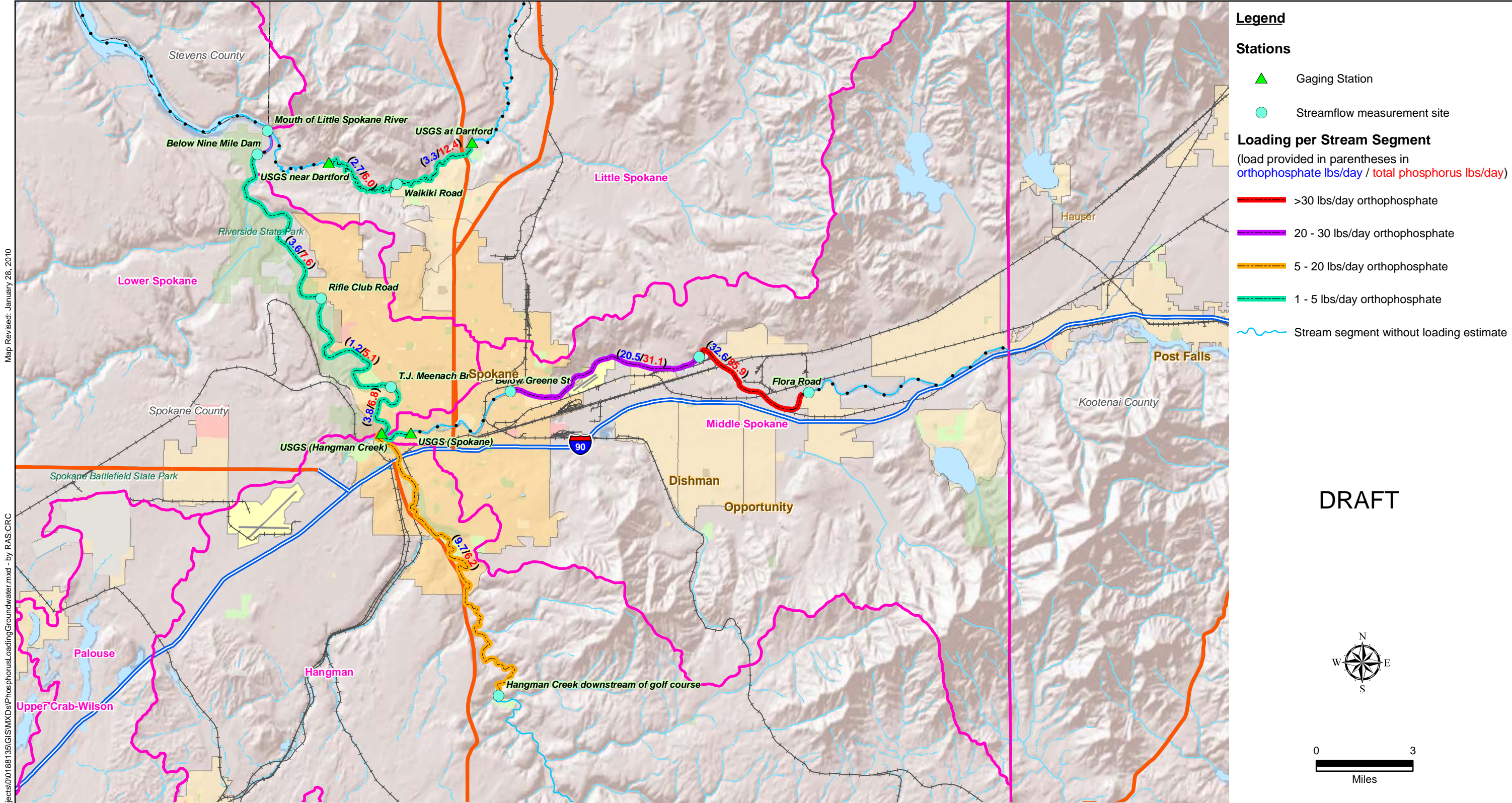
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3. Future revisions of this figure may show different data.

Well Locations

Nonpoint Source Phosphorus Study
Spokane County, Washington



Figure 2



Legend

Stations

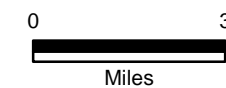
- ▲ Gaging Station
- Streamflow measurement site

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

DRAFT



Map Revised: January 28, 2010

Path: \\SPO\Projects\00188135\GIS\MXDs\Phosphorus>LoadingGroundwater.mxd - by RAS,CRC

Office Location: SPO

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

Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. Future revisions of this figure may show different data.
4. lbs/day = pounds per day

Phosphorus Loading from Groundwater

Nonpoint Source Phosphorus Study
Spokane County, Washington



Figure 3



APPENDIX A **References**

APPENDIX A REFERENCES

GeoEngineers, Inc., 2009a, Preliminary Groundwater Loading Analyses, Bi-State Nonpoint Source Phosphorus Study. Prepared by GeoEngineers, Inc., Spokane, Washington for Spokane County Department of Utilities, Spokane, Washington, August 4.

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Hsieh, P.A., Barber, M.E., Contor, B.A., Hossain, M.A., Johnson, G.S., Jones, J.L., Wylie, A.H., 2007, Groundwater Flow Model for the the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho. USGS Scientific Investigations Report 2007-5044.