## Table 3. Lake Sample Collection Schedule

| Parameters | Field/Lab Analysis (F,L)* | Frequency (W,T,M,Q)** May - Sept | Oct - Apr | Depth Location (S,M,B)*** |
|---|---|---|---|---|
| Secchi disk transparency | F | W**** | M | - |
| Temperature | F | T | M | 1-meter intervals |
| Dissolved Oxygen | F | T | M | 1-meter intervals |
| Total Phosphorus | L | T | M | S,M,B |
| Soluble Reactive Phosphorus | L | T | M | S,M,B |
| Total Kjeldahl Nitrogen | L | M | Q | S |
| Ammonia Nitrogen | L | M | Q | S |
| Nitrite + Nitrate Nitrogen | L | M | Q | S |
| Total Suspended Solids | L | T | - | S |
| Total Suspended Volatile Solids | L | T | - | S |
| Total Alkalinity | L | Q | Q | S |
| Chloride | L | Q | Q | S |
| Color | L | Q | Q | S |
| pH | L | T | M | S |
| Conductivity | L | T | M | S,B |
| Chlorophyll *a* (pheophytin Corr.) | L | T | M | S |
| Phytoplankton | L | T | - | S |
| Zooplankton | L | T | - | Vertical column |
| Fecal Coliform Bacteria | L | Q | Q | S |
| Fisheries Survey | F | DNR data summarized | | - |
| Vascular Plant Survey | F | - | - | - |

## Table 4. Stream Sample Collection Schedule

| Parameter | Field/lab Analysis | Baseline Frequency Apr - Sept | Oct - Mar | Number of storm events† |
|---|---|---|---|---|
| Total Phosphorus | L | T | M | 6 |
| Soluble Reactive Phosphorus | L | T | M | 6 |
| Total Suspended Solids | L | T | M | 6 |
| Total Suspended Volatile Solids | L | T | M | 6 |
| Temperature | F | T | M | 6 |
| Conductivity | L | Q | Q | 6 |
| Total Kjeldahl Nitrogen | L | T | M | 6 |
| Ammonia Nitrogen | L | T | M | 6 |
| Nitrite + Nitrate Nitrogen | L | T | M | 6 |
| Fecal Coliform Bacteria | L | Q | | |
| Water Level (stage) | F | continuous†† | | |

*: F - field, L - laboratory

**: W - weekly, T - twice a month, M - monthly, Q - quarterly

***: S - surface, M - metalimnion, B - bottom (1.0 meter off the bottom)

****: Secchi disk measurements were also part of the Citizen's Lake Monitoring Program

†: An automatic sampler was used to collect samples during rainfall events. Samples were collected at discrete time intervals and composited according to the hydrograph.

††: Continuous stage recorders were installed at the lake inflow and outlet sites

### 1.1.3 Precipitation/dry fall monitoring

Rainfall on the watershed was measured at six sites (Figure 4a). The two major inlets were equipped with Texas Instrument model TE525 tipping bucket rain gauges. Two sites, Loretto City Hall and Greenfield City Hall were equipped with 14" model 401 All Weather plastic bulk rain gauges with graduations for each .01" of rain. A bulk rain gauge was also located at Baker Park Reserve behind the Natural Resources Department building and at the Baker Park Golf Course. Precipitation monitoring began in the fall of 1990 and was completed in October 1991. Precipitation samples were collected at the two stream sites on three dates and were analyzed for total phosphorus and total Kjeldahl nitrogen. Equipment problems resulted in no rainfall data collected at station 4 from July to September 1991.

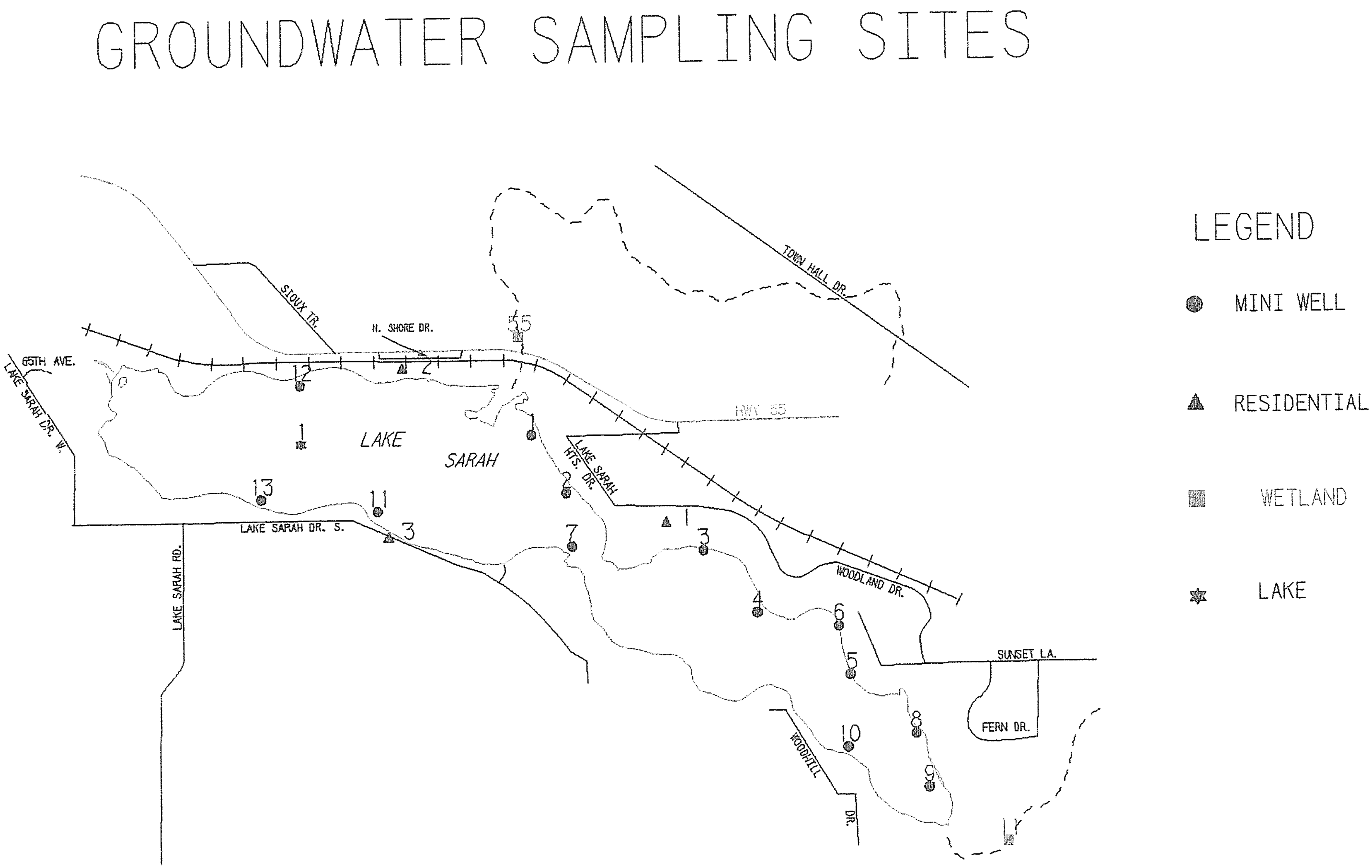
Snow pack samples were collected from 3 sites in the watershed. Samples were collected using a 2" PVC pipe. Several cores were composited in a container. The melted snow was analyzed for total phosphorus, pH, alkalinity, conductivity, cations/anions, and stable isotopes.

Flow data and tipping bucket rain gauge data was downloaded using a lap top computer with ISCO Teleflow-lapcomm-analyst software. Twelve volt deep cycle batteries were used to provide power to the equipment. Watershed precipitation was calculated using Thiessen Polygons.

### 1.1.4 Groundwater/septic system monitoring

Groundwater monitoring was conducted with the help of MPCA staff. Sampling was conducted on two separate dates. The work plan called for use of the MPCA's Septic Leachate Detector. However, due to equipment problems the groundwater monitoring plan was altered. The first monitoring occurred in July 1991 using MPCA's mini sandpoint well and a peristaltic pump. The mini well was pushed into the sediment a minimum of about six inches and the peristaltic pump was turned on. If groundwater was pulled, samples were analyzed for cations/anions, total phosphorus, conductivity, redox, pH, alkalinity. The second round of sampling was conducted on February 24 and 27, 1992. It included 3 sites from the previous round, three residential wells, lake and wetland samples and snow samples (Figure 4b). These samples were analyzed for stable isotopes in addition to the parameters analyzed in the first round of sampling. The sampling methods are described in Appendix 1.

**Figure 4b. Groundwater Sampling Sites**



### 1.1.5 Macrophyte survey

The aquatic macrophyte survey was conducted on July 29 and 30, 1991 using the DNR's method (DNR, 1989). Six north-south transects across the lake were surveyed. Shoreline vegetation was examined and species recorded. Submergent vegetation was determined using a six tine grapple hook. The grapple hook was tossed in all four directions from the boat and pulled back toward the boat. Each toss was consistent using 20 feet of rope. The transects were surveyed from the shoreline out to a depth where no plants were found. Vegetation on the grapple hook was identifiedSpecies and density were recorded. Plant density was calculated by dividing the number of casts from which a species is recovered by the number of casts per location.

### 1.1.6 Watershed assessment

The Lake Sarah watershed was initially delineated on USGS quad maps. These lines were field verified by windshield survey, walking the site and surveying culvert elevations. Land use information was obtained using Hennepin Conservation District's Geographic Information System (GIS). Land use data from 1989 was used to determine the land use percentages. Windshield surveys were used to verify major land uses in the watershed.

### 1.1.7 Data management and statistics

The dataloggers in the ISCO flow meters were read using a Toshiba 1200 lap top computer equipped with Teleflow-lapcomm-analyst software. The flow and nutrient data was entered into Lotus 123 spreadsheets. Personal computers at the Hennepin Parks and Hennepin Conservation District offices were used for the data compiling and analysis. The computer models, Minleap, Reckhow and Simpson, Flux and Bathtub were used on the data.

### 1.1.8 Quality control/quality assurance

Quality control/quality assurance was maintained in accordance with the MPCA approved Monitoring Plan which included the QAPP. The flow meters were checked against a portable velocity meter provided by the MPCA. Staff gauges were read along with the flow meters to verify and back up the data. The laboratory, Instrumental Research also has an MPCA approved QAPP. Duplicate zooplankton samples were enumerated for quality assurance purposes.

### 1.1.9 Water modeling techniques

The lake quality models, Minleap, Reckhow and Simpson and Bathtub were used on the Lake Sarah Project data. Flux was used to reduce the flow monitoring and sample data. Land use data and acreage was taken from Hennepin Conservation District's GIS. The Apollo computer system with Ultimap software was used. Land cover was digitized from 1989 half-section aerial photo maps. The areas were defined and acreage determined using GIS. Runoff coefficients were estimated for un-gauged areas (Chow, 1988).

## 2.0 RESULTS

## 2.1 Project Area

### 2.1.1 Existing land use

The Lake Sarah Watershed can be characterized as primarily agriculture and rural residential. The distribution of land uses is listed in Table 5.

**Table 5. Lake Sarah Land Use**

| Land Use | Acreage | Percent |
|---|---|---|
| Crop | 1966.4 | 42.7% |
| Grassland/pasture | 683.9 | 14.8% |
| Farmsteads | 130 | 2.8% |
| Wetlands | 704.3 | 15.3% |
| Transportation | 275.1 | 6% |
| Woods | 209.5 | 4.5% |
| Park land(Loretto) | 14.5 | 0.3% |
| Dwellings | 570.3 | 12.4% |
| Commerce | 54.5 | 1.2% |
| TOTAL | 4608.5 | 100% |

### 2.1.2 Soils and geology

Soils in the watershed are predominantly Erin and Hayden loams and clay loams. Maximum relief in the project area is approximately 100 feet. Detailed soil and topographic data are included in the Pioneer-Sarah Creek Watershed Management Plan. Soils in the upper part of the watershed in Greenfield are of the Hayden-Cordova-Peaty muck association. This association is described as nearly level to rolling, medium-textured soils that developed in glacial till, and level organic soils. The soils around the lake and to the south are of the Erin-Kilkenny-Peaty muck association. They are described as gently undulating to hilly, medium-textured and moderately fine textured soils that developed in glacial till, and level organic soils. The soils of this association have severe limitations for the use of onsite sewage disposal systems, because of moderately low percolation rates and the high water table or shrink-swell potential (USDA, SCS 1974). Lake Sarah is a type 4 ice block basin in till localized in preglacial valleys (Zumberge 1952).

Many of the soils immediately surrounding the lake are wet soils in shallow basins on the glacial till plains. These soils are generally wet all year 0-1 feet below the surface and are subject to ponding.

### 2.1.3 Precipitation and climate

Precipitation for the year of the study, 1991, was above normal. Average precipitation is 29 inches. In 1991, the watershed received 33 inches. The average annual temperature in the area is 44 °F (7°C). The normal annual snowfall is 43 inches (1092 mm). The average growing season occurs between May 7th and October 5th, a period of 152 days (HCD, 1986).

### 2.1.4 Population characteristics

The Lake Sarah watershed lies within 5 cities, Greenfield, Independence, Loretto, Corcoran and Medina. The majority of the watershed (79%) lies within the cities of Greenfield and Independence. The 1991 population of these cities was approximately:

| | |
|---|---|
| Independence | 2,822 |
| Greenfield | 1,450 |
| Loretto | 404 |
| Corcoran | 5,199 |
| Medina | 3,096 |

The estimated population of the project area is 1,350 with an estimated population of 5,000+ benefiting from the project. These cities which have agriculture as the primary land use, are slowly developing. Some areas are being rezoned as residential with large lot sizes such from 1/40 to 1/5 acres. The population will grow steadily as these agricultural lands are converted to residential. Use of Lake Sarah for recreation will increase as more families move into the area. The agricultural area on the south side of the lake is presently undergoing development as approximately 5 acre residential lots. Some of this area drains to Lake Sarah. Development is also occurring on the southeast end of the lake, along Loretto Creek and north of Highway 55.

### 2.1.5 Land ownership

Present land ownership is fairly large parcels with the exception of some small developments and the lots around the lake. Hennepin Parks owns some land around and near Lake Sarah designated as the Lake Sarah Recreation Park. There are presently no facilities in the park land. Some of the large parcels are being proposed for subdivision. In 1991 there was one resort, 12 cabins, 129 homes and 3 farms on the lake (DNR Fisheries Survey, 1991). The resort has since been sold and split off into several individual lots.

### 2.1.6 Community water and sewer supplies

The water supply for the watershed homes and businesses is private wells. These wells vary in depth from approximately 50 to 260 feet. Some of the homes in the watershed are connected to city sewer. These homes are around Lake Sarah. Most of the homes in Greenfield are hooked up. The lines carry liquid wastes for treatment. Each home still has a 1000 gallon septic tank, a 1500 gallon combination septic and pumping tank and a pump with float switching. This system must be periodically maintained. The City provides for inspections and pumping of these tanks. In 1991, 81 homes on the Independence side of the lake had individual on-site septic systems. In 1994, the City of Independence provided additional hookups for the remaining existing homes. These homes also must maintain septic tanks. Only a few homes on the southwest part of the lake in Greenfield are without hookups. The homeowners have made arrangements to upgrade their systems. The City of Independence provides a list of contractors that are permitted to provide septic tank pumping services in the City.

### 2.1.7 Point sources

The Woodlake Sanitary Landfill is in the vicinity of Lake Sarah. However, it is not located within the watershed. Based upon discussions with MPCA staff, it appears that groundwater from the landfill would not affect lake Sarah. There are no wastewater treatment plants within the watershed. A few small commercial and industrial sites are located within the watershed in the City of Loretto. None of these has been identified as contributing point source pollutants to the lake.

### 2.1.8 Description of Lake Sarah

Lake Sarah has the following morphometric characteristics:

**Table 6. Lake Sarah Characteristics**

| Description | Size | Fetch | Maximum Depth |
|---|---|---|---|
| Lower Basin (northwest) | 347 acres | 1.5 miles | 60 feet |
| Upper Basin (southeast) | 205 acres | 1.4 miles | 40 feet |
| Total Lake | 552 acres | 2.3 miles | 60 feet |
| Shoreline length | 8.2 miles | 13.2 km | |
| Mean depth | 18.2 feet | 5.5 meters | |
| NOHWM | 979.5 feet | | |
| 100 year flood elevation | 981.1 feet | | |
| Long term fluctuation | ±2.0 feet to unknown | ± 0.6 meter | |
| Annual fluctuation | ± 1.0 foot | ± 0.3 meter | |
| Average Hydraulic Residence Time | 2.1 years | | |
| Lake volume | 9584 acre-feet | 11.8 $hm^3$ | |
| Littoral area | 371 acres | 65% of total area | |

## 2.2 Lake Data

### 2.2.1 Water quality

Lake Sarah lake water quality data for 1991 is presented in Table 7 and Figure 5. The summer (May - September) mean epilimnetic (surface) total phosphorus concentration was 111 µg/l for the upper basin and 104 µg/l for the lower basin. The soluble reactive phosphorus concentration for the upper basin averaged 49 µg/l and for the lower basin averaged 39 µg/l. Transparency averaged 1.3 meters (4.2 feet) and 1.4 meters (4.6 feet) for the upper and lower basin respectively. Chlorophyll *a* concentrations in the lake were 19 µg/l and 22 µg/l. Hypolimnetic total phosphorus concentrations were significantly higher. Concentrations of 383 µg/l and 380 µg/l for the upper and lower basins were measured. The water quality averages for the entire lake were 1.3 meters (4.3 feet) transparency, 108 µg/l TP and 20.4 µg/l chlorophyll *a*.

There was very little variability between the two basins of the lake. In the future, sampling the lower basin, rather than both basins, will provide a good estimate of the water quality for the lake. Total phosphorus was unusually high in the lake in 1991, the highest on record. The 1992 mean TP was 93 µg/l measured in the lower basin. In 1994, the mean TP was 57 µg/l.

#### 2.2.1.1 Temperature and Dissolved Oxygen

The Dissolved Oxygen and temperature profiles were measured from January-October (Figures 6 and 7). Lake Sarah was stratified during the January and February monitoring. Spring turnover occurred and the lake was mixed by April 17, 1991. The lake was weakly stratified on May 22. In June anoxia occurred at about 11 meters at site 1 and 9 meters at site 2. In July anoxia occurred below a depth of 4-7 meters. By August the lake was anoxic below 5-6 meters. In early September anoxia occurred below 7 meters. By late September the lake was weakly stratified with anoxia below 9 meters. Mixing occurred by the October 8, 1991 sampling date.

During periods when the lake was stratified, the lake became anoxic in the hypolimnion. Internal loading is possible when the hypolimnion becomes anoxic. The high total phosphorus in the hypolimnion indicates internal loading. The higher concentration hypolimnetic waters may be carried into the epilimnion during wind mixing or turnover.

## Table 7. Lake Sarah Water Quality 1991

**Upper Basin**

| Date | SDT meters | TP µg/l | SRP µg/l | TP-SRP µg/l | CHL µg/l | TKN µg/l |
|---|---|---|---|---|---|---|
| 17-Jan | | 111 | 79 | 32 | 1.5 | 1145 |
| 19-Feb | | 145 | 115 | 30 | 2.63 | |
| 19-Mar | | 244 | 37 | 207 | 10.5 | 1023 |
| 17-Apr | 1.07 | 146 | 3 | 143 | 36.9 | 1354 |
| 8-May | 1.3 | 101 | 27 | 74 | 15.98 | 794 |
| 22-May | 3.05 | 57 | 35 | 22 | 4 | 643 |
| 5-Jun | | 116 | 63 | 53 | 7.1 | 636 |
| 18-Jun | 1.4 | 185 | 70 | 115 | 14.9 | |
| 8-Jul | 0.79 | 145 | 50 | 95 | 21.3 | 479 |
| 23-Jul | 0.76 | 126 | 39 | 87 | 28 | |
| 5-Aug | 0.98 | 91 | 40 | 51 | 23.2 | 741 |
| 19-Aug | 1.34 | 39 | 20 | 19 | 16.6 | |
| 5-Sep | 0.85 | 43 | 12 | 31 | 27.3 | |
| 19-Sep | 0.79 | 211 | 135 | 76 | 28.7 | |
| 8-Oct | 0.95 | 178 | 122 | 56 | 35.4 | 852 |
| Mean (total) | 1.21 | 129 | 56 | 73 | 18.3 | 852 |
| Stdev | 0.65 | 59.6 | 41 | 52 | 12 | 277 |
| Confidence Interval | 0.39 | 30.2 | 21 | 26 | 6 | 181 |
| Mean (March-Oct) | 1.21 | 129 | 50 | 79 | 20.8 | 815 |
| Stdev | 0.65 | 64 | 39 | 53 | 10 | 271 |
| Confidence Interval | 0.37 | 35 | 21 | 29 | 6 | 148 |
| Mean (May - Sept) | 1.25 | 111 | 49 | 62 | 19 | 659 |
| Stdev | 0.72 | 58 | 35 | 32 | 9 | 121 |
| Confidence Interval | 0.47 | 36 | 22 | 20.1 | 5.3 | 74.72 |

## Table 7. Lake Sarah Water Quality 1991 (continued)

**Lower Basin**

| Date | SDT meters | TP µg/l | SRP µg/l | TP-SRP µg/l | CHL µg/l | TKN µg/l | TN µg/l | ON µg/l | IN µg/l | TSS µg/l | TVSS µg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 17-Jan | | 108 | 77 | 31 | 0.3 | 1129 | 1178 | 876 | 302 | | |
| 19-Feb | | 145 | 111 | 34 | 2.26 | | | | | | |
| 19-Mar | | 223 | 27 | 196 | 8.5 | 719 | | | | | |
| 17-Apr | 1.34 | 140 | 19 | 121 | 36.2 | 1280 | 2326 | 980 | 1346 | | |
| 8-May | 1.74 | 87 | 23 | 64 | 17.45 | 856 | 1638 | 454 | 1184 | 2600 | 2400 |
| 22-May | 3.05 | 62 | 19 | 43 | 3.5 | 572 | 641 | 383 | 258 | 900 | 800 |
| 5-Jun | 2.38 | 117 | 58 | 59 | 5.5 | 465 | 566 | | 682 | 800 | 800 |
| 18-Jun | 1.31 | 134 | 45 | 89 | 22.2 | | | | 812 | 6500 | 6100 |
| 8-Jul | 0.73 | 128 | 38 | 90 | 32 | 725 | 1869 | 619 | | | |
| 23-Jul | 0.73 | 113 | 23 | 90 | 25.3 | | | | 1320 | 4200 | 3600 |
| 5-Aug | 1.01 | 75 | 24 | 51 | 38.2 | 768 | 1564 | 752 | 304 | 8700 | 8400 |
| 19-Aug | 1.16 | 42 | 12 | 30 | 17.3 | | | | | 5700 | 5500 |
| 5-Sep | 0.76 | 47 | 15 | 32 | 33.7 | 980 | 1445 | 125 | | 15500 | 13000 |
| 19-Sep | 0.82 | 237 | 133 | 104 | 25.7 | 646 | 864 | 560 | | 3800 | 1800 |
| 8-Oct | 1.07 | 182 | 123 | 59 | 29.6 | | | | | 10900 | 6100 |
| Mean (Jan - Oct) | 1.34 | 123 | 50 | 73 | 19.8 | 814 | 1343 | 594 | 776 | 5960 | 4850 |
| Stdev | 0.72 | 58.2 | 41.5 | 44.6 | 13.1 | 252 | 585 | 278 | 465 | 4650 | 3833 |
| Confidence Interval | 0.41 | 29.5 | 21.0 | 22.6 | 6.6 | 156.4 | 382.5 | 192.3 | 322.2 | 2882 | 2376 |
| Mean (March-Oct) | 1.34 | 122 | 43 | 79 | 22.7 | 779 | 1364 | 553 | 844 | 5960 | 4850 |
| Stdev | 0.72 | 62 | 40 | 45 | 11.6 | 241 | 622 | 273 | 458 | 4650 | 3833 |
| Confidence Interval | 0.41 | 34 | 22 | 24 | 6.3 | 149 | 407 | 189 | 317 | 2748 | 2206 |
| Mean (May - Sept) | 1.37 | 104 | 39 | 65 | 22 | 716 | 1227 | 482 | 760 | 5411 | 4711 |
| Stdev | 0.79 | 57 | 36 | 27 | 11 | 174 | 525 | 217 | 439 | 4575 | 4039 |
| Confidence Interval | 0.49 | 35 | 22 | 17 | 7 | 108 | 325 | 134.5 | 272.1 | 2835.6 | 2503.3 |