

## VI. GREENWOOD LAKE DREDGING PLAN

### VI. GREENWOOD LAKE DREDGING PLAN

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**(2010)**

*“Project 3”, the development of a plan to dredge portions of the New Jersey end of Greenwood Lake, was carried out by consultants, HydroQual and associates, during 2010. Their recommendations are reported in a separate report entitled “Greenwood Lake Dredging Plan” and summarized below.*

#### A. INTRODUCTION

Greenwood Lake is located in Passaic County, New Jersey and Orange County, New York. The lake is one of the largest lakes within the Highlands region of northern New Jersey. The lake is bounded to the north by the Town of Warwick and Village of Greenwood Lake in New York and to the south by the Township of West Milford in New Jersey. The lake is approximately nine miles long and has a maximum width of approximately 0.7 miles. The lake itself encompasses approximately 1,884 acres and consists of two uniquely different basins. The New York portion of the lake is much deeper than the New Jersey side of the lake with water depths up to approximately 60 feet and steeply sloped banks. In contrast, the southern portion of the lake has a maximum depth of approximately 10 feet and is characterized by gradually sloping banks. The watershed drainage area to the lake is approximately 16,036 acres and approximately 80% is forested with the balance consisting of primarily residential and commercial uses. Several streams also flow into the lake with the largest being Belcher Creek located in the southwestern portion of the lake. The eastern and western limits of the lake are characterized by steep mountain ridges which parallel the lake shoreline.

The lake provides a source of high quality raw water and is the headwaters of the Wanaque River which drains to the Monksville and Wanaque Reservoirs which represent a critical component of the public drinking water supply for a significant portion of northern New Jersey, approximately 3.5 million people. The Wanaque River drainage area, inclusive of Greenwood Lake, and the catchment area specific to the Monksville Reservoir are the primary inflows to this reservoir. As a result, maintenance and improvement of water quality within Greenwood Lake is important to these downstream public water supplies.

#### B. WATER QUALITY CHALLENGES

Greenwood Lake was originally a vacation destination, but over the past 50 or more years has evolved into a year-round community. These changes, in conjunction with increased development in the surrounding watershed, have impacted the water quality of the lake due to septic systems originally constructed for seasonal residents, increased runoff and the pollutant loadings associated with these.

Since the mid-1970's, several studies have characterized and quantified pollutant loads and water quality problems within Greenwood Lake. Several actions have been implemented over this period to directly address Greenwood Lake's water quality and resource value problems. Lake drawdowns, weed harvesting, stump reduction efforts, development of new ordinances to address

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septic system pollution, and implementation of several stormwater management initiatives have been undertaken by the Greenwood Lake Commission and other committed stakeholders.

Greenwood Lake was also identified as impaired by the New Jersey Department of Environmental Protection (NJDEP) and New York State Department of Environmental Conservation (NYSDEC) primarily due to nutrients. A Total Maximum Daily Load (TMDL) for phosphorus was prepared by the NJDEP in 2004. The NJDEP indicated that Greenwood Lake is impaired because it is eutrophic, “as evidenced by elevated total phosphorus, elevated chlorophyll-a, and/or macrophyte (e.g., aquatic vegetation) density that impairs recreational use.” As the lake has been listed as impaired for phosphorus, the TMDL was prepared to specify the phosphorus load reductions required to eliminate the impairment and thus restore the Lake’s water uses. An integral component of the TMDL is implementation of actions that will reduce pollutant loads to the required levels.

### C. CURRENT STUDY

As part of a larger plan for the improvement of Greenwood Lake originally presented within the Phase I Diagnostic Feasibility Study and Clean Lakes Study completed in the 1980s, several action items were established for future implementation. These were intended to reduce ongoing degradation of water quality within Greenwood Lake and included:

- ◆ Upgrade of existing sewage treatment plants (STP) with discharges to the lake or its tributaries;
- ◆ Development of septic management districts to monitor existing septic systems and establish improved design specifications for new systems;
- ◆ Development of a comprehensive stormwater management plan;
- ◆ Implementation of a site plan review committee to evaluate new development within the watershed;
- ◆ Increased public education;
- ◆ Periodic weed harvesting;
- ◆ Periodic lake drawdowns for the management of nuisance aquatic vegetation; and
- ◆ Dredging.

Dredging was identified as one of the action items, as it was understood that among the potential sources of nutrients to the lake, and in particular phosphorus, were existing, organic-rich sediments within the lake. The 2004 TMDL noted that recycling of nutrients from these sediments was one of the more significant sources of phosphorus. These nutrients have contributed to the growth of nuisance vegetation within the lake which has impacted recreational opportunities and contributes to the ongoing eutrophication of the lake.

The current study was prepared to develop a proposed conceptual dredging plan for the New Jersey portion of Greenwood Lake. This plan establishes the framework for future work efforts that the Commission may wish to undertake with regard to the dredging of one or more locations within Greenwood Lake. The proposed dredging plan encompasses the following components:

- ◆ Identification of potential dredging locations.
- ◆ Recommendation of a dredging method appropriate to these sites.
- ◆ Determination if post-dredging processing (e.g. dewatering, stabilization, etc.) may be required, if potential locations proximate to the lake are available, and if these possess sufficient acreage.

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- ◆ Identification of potential disposal or beneficial use alternatives for the management of dredged material.
- ◆ Development of an order of magnitude estimate of proposed dredging and the cost for this based upon a proposed dredging depth.

### D. GOALS OF DREDGING

Development of a dredging plan and subsequent dredging of Greenwood Lake would serve to meet several goals of the Greenwood Lake Commission and the surrounding communities, while addressing many of the action items identified within the Clean Lakes Study and recently reiterated in the 2005-2006 Greenwood Lake Commission Progress Report. Appropriate dredging in Greenwood Lake can help to address the following problem issues.

#### **Nuisance Aquatic Vegetation**

Greenwood Lake has had ongoing problems with emergent macrophytes for many years. Nutrients that are already present within the lake or are still being discharged to the lake and its watershed from point (i.e. STPs) or non-point sources (e.g., failing septic systems, stormwater runoff) have contributed to this problem. Prior reports emphasized the preponderance of aquatic macrophytes in the lake's southern region. The abundance of aquatic plants and algae in the lake's southern basin is due to the lake's morphometry and the nature of the substrate. Subsequent monitoring and analysis have confirmed that this region is also close to major inputs of sediment and nutrients needed to support plant growth.

The lake is impacted by several species of aquatic vegetation that affect water quality, aesthetics, and navigation and contribute to the ongoing accumulation of organic-rich sediments. Several areas of the lake that have limited water circulation, significant stormwater or other nutrient inputs and/or accumulated organic-rich sediments have ongoing problems with aquatic vegetation. This includes several coves along the shoreline of the lake, several arms or reaches within the northern portions of the lake in New York, and a large area at the southernmost end of the lake that is located in proximity to Belcher Creek. Primary nuisance species of concern within the lake based upon previous studies and discussions with the Commission include Eurasian water-milfoil, Carolina fanwort, Big-leaf pondweed, Fernleaf pondweed and Curly-leaf pondweed.

Dredging can be utilized as a potential method for the management of nuisance aquatic vegetation. However there are limitations to this that are dependent upon the specific water body. Aquatic vegetation requires nutrients, but more importantly requires light penetration. Dredging will remove rooted aquatic plants along with sediments. Consequently, dredging can improve the recreational and aesthetic quality of Greenwood Lake. The effectiveness and longevity of dredging as a control measure for aquatic macrophytes, however, depends on several inter-related factors: the extent of dredging and the lake bottom bathymetry after dredging is completed, water clarity and light penetration, the texture and nutrient status of the lake bottom after dredging is completed, and the nature of the macrophyte community. Implementation of dredging as part of an overall program for the management of aquatic vegetation was therefore one of the primary goals for the dredging.

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### **Nutrient Control**

Dredging areas of existing, organic-rich sediments in conjunction with the ongoing efforts of the Greenwood Lake Commission and surrounding communities to reduce pollutant inputs to the lake can serve to reduce potential sinks that contribute to ongoing water quality issues. Removal of these organic-rich sediments from specific areas within the lake was identified as another key goal for the implementation of dredging.

### **Water Supply and Flood Control**

Greenwood Lake drains to the Wanaque River and the Monksville and Wanaque Reservoirs, significant public drinking water supplies for approximately 3.5 million people in northern New Jersey. Water flows from Greenwood Lake and the Wanaque River are the primary sources of inflow to the Monksville Reservoir with the exception of the catchment area of the reservoir itself. Maintenance and improvement of water quality within Greenwood Lake has a direct impact to these downstream reservoirs. Dredging within Greenwood Lake for the improvement of water quality would therefore provide a tangible benefit to these water supplies.

As a result of the largely undeveloped nature of Greenwood Lake's watershed, the lake has historically provided a significant source of high quality raw water that is an important resource to downstream reservoirs. Maintenance and improvement of water quality within Greenwood Lake is therefore of critical importance to these reservoirs. Implementation of dredging within the lake would serve to improve water quality by reducing organic-rich sediments that have been contributing to the ongoing degradation of water quality.

Improvement of water quality would allow Greenwood Lake to continue to represent a source of high quality raw water for downstream reservoirs. Dredging would also increase the overall storage capacity of Greenwood Lake. Ongoing sedimentation due to stormwater runoff, the accumulation of decaying organic materials (i.e. aquatic weeds) and other sources has been slowly decreasing the overall storage capacity of the lake. Thus dredging would provide an increase in the storage capacity of the lake, thereby adding additional capacity for potential flood control and increasing the potential supply of water that could be made available to downstream reservoirs. This would result in a potential increase in the availability of high quality raw water for these reservoirs within northern New Jersey. As a result, benefits to existing public water supplies and potential flood control were also identified as goals that would be achieved by dredging.

### **Navigation**

Greenwood Lake is comprised of two very different sub-basins. The New York portion of the lake in general has much deeper waters, while the New Jersey side of the lake is much shallower. In addition, substantial areas of the latter portion of the lake possess large submerged stump fields that impact navigation. Stump fields and additional locations that have accumulated sediment over time combined with the generally shallower water depths within the New Jersey portion of the lake have presented navigation issues. These areas present challenges to recreational boaters and in some instances result in damage to vessels. In addition, many of these same areas are also impacted by nuisance vegetation which has also adversely affected navigation.

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### Lake Management

Lake management currently includes lake drawdown activities, but also the maintenance or improvement of recreational opportunities within the lake, such as swimming and improved habitats. The Greenwood Lake Commission and surrounding communities currently conduct periodic drawdowns (approximately every four years) of the lake for the management of aquatic macrophytes and to allow for the maintenance of waterfront structures. The current drawdown is five feet, although investigation of potential future drawdowns of seven feet is being considered. Additional drawdown would potentially result in a further reduction of nuisance aquatic vegetation. Potential obstacles to the efficient drawdown of the lake under current or future operational scenarios, was therefore taken into account as part of the dredging plan.

## E. PROPOSED DREDGING PLAN

### Introduction

Based upon a review of available information, an evaluation of potential alternatives, preliminary field investigations and hydrographic surveys, a proposed dredging plan was prepared for Greenwood Lake. The primary goals for the dredging plan were focused upon the reduction of existing nutrients within the lake, the management of nuisance aquatic vegetation, the potential increase in the capacity of the lake for water supply and flood control purposes, improvements in existing navigation and facilitation of ongoing lake management activities.

### Dredging Plan Development

A total of six locations were identified and prioritized as candidate dredging sites. These areas of potential dredging are shown in Figure VI-1. These sites were primarily identified based upon existing conditions (e.g., nuisance vegetation) and water depths. Sites were prioritized based upon the overall goal of improving water quality, which would be a benefit to the surrounding communities and would ensure that Greenwood Lake continues to represent a high quality source of raw water for downstream public water supplies. Reduction of organic-rich sediments and nuisance aquatic vegetation were therefore very important in this regard.

**Browns Point/Belcher Creek** areas are the primary candidate sites for dredging. These areas are known to contain organic-rich sediments, are located within a region of the lake that has previously been identified as a significant source of nutrients, has ongoing aquatic vegetation impacts and navigation issues related to shallow water depths and vegetation. This is also the largest candidate area and dredging would result in a significant increase in the capacity of the lake of up to 193 million gallons (see Table VI-1).

The **Outlet Dam** was ranked second. The dam area is used for the control of lake levels during drawdowns. Concerns related to shallow water depths in proximity to the outlet dam were identified due to their potential adverse impact upon drawdown activities. Results of hydrographic surveys generally showed water depths of 6 to 10 feet with some shallower areas closer to the dam that were two to four feet deep. As existing water depths were greater than originally anticipated, the ranking of this site was reduced. Dredging at this location would also increase lake capacity.

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**Rocky Cove** and the **Unnamed Cove** south of Greenwood Small Craft Marina represent the next highest ranked sites. These locations are also impacted by aquatic vegetation and it is anticipated that this problem has contributed to sediment accumulation and an increase in organic material within these locations from annual weed die offs.

Dredging of the channels adjacent to **Fox Island** and **Storms Island** was determined to be the lowest priority of the six candidate areas. Dredging within these areas would primarily be directed towards an improvement in existing navigation depths. Hydrographic surveys generally indicated water depths between six to seven feet. Dredging of these locations would also result in an increase in lake capacity.

### Proposed Dredging Depth

An existing and maintained baseline water depth does not currently exist for Greenwood Lake. There is also not necessarily a fixed dredging depth that would result in the complete elimination of aquatic nuisance vegetation. Based upon the results of hydrographic surveys that generally showed water depths that ranged from four to seven feet within the six candidate dredging locations, a depth of 10 feet (as measured from the crest of the outlet dam) was initially identified as the proposed project depth. The 10-foot elevation would correspond to a dredge elevation of 608 feet NAVD88. Refinement of the project depth for individual locations may be warranted as the plan is implemented.

### Proposed Dredging

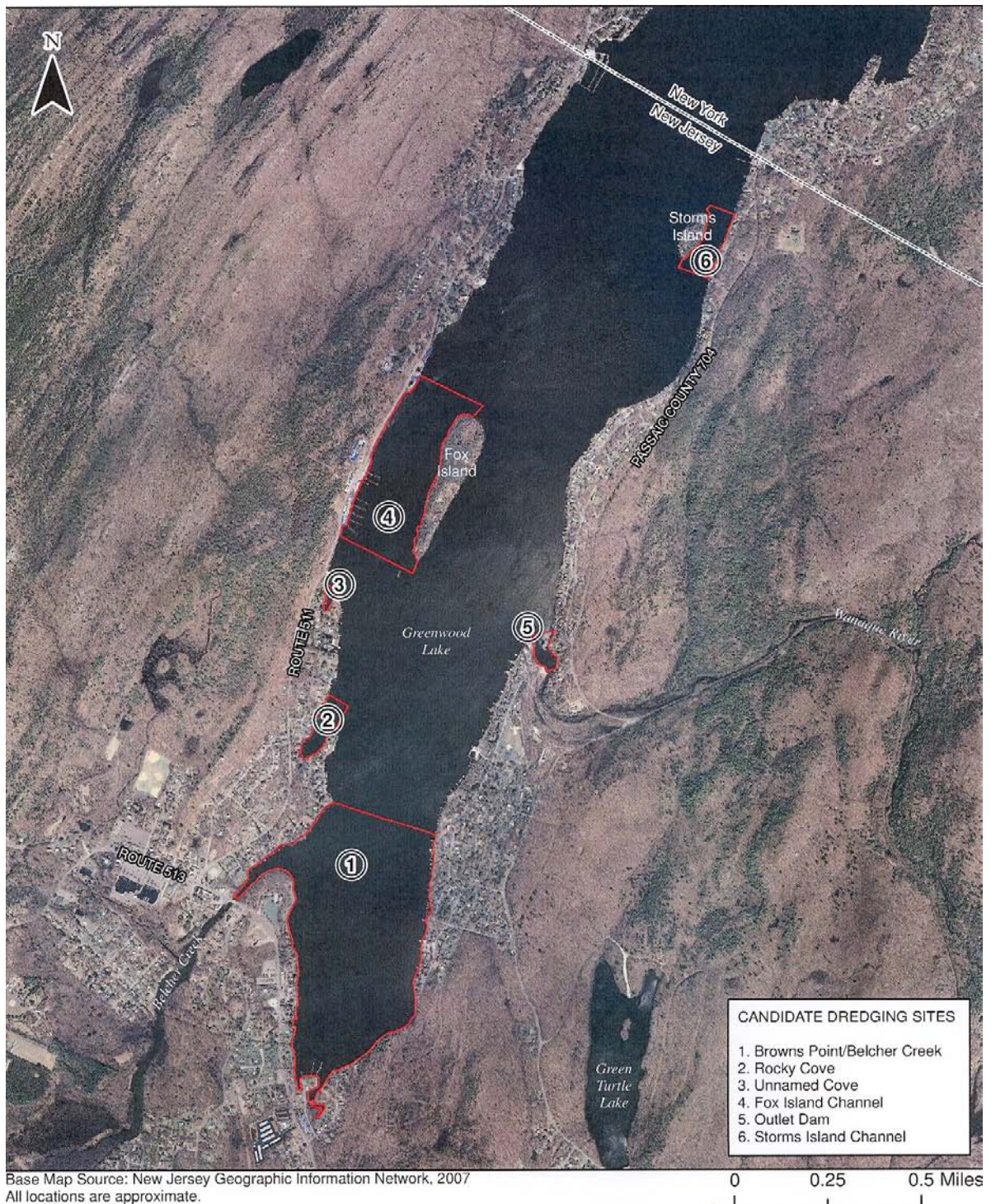
Three dredging methods were evaluated for Greenwood Lake and **mechanical dredging** with the use of a clamshell bucket is recommended. This method allows dredging to occur where access may be limited due to water depth or environmental concerns. Mechanical dredging also allows for multiple transportation and rehandling options. Equipment for mechanical dredging would be transported to the sites through the use of a Flexifloat work platform system. Dredged material would be placed into 20-30 cubic yard scows. A conservative estimate for dredged material transloading on a daily basis would be on the order of 500-2,000 cy with an estimate of 1,000 cy considered conservative.



**Hydraulic dredging** was generally ruled out due to the required transport distances from the point of dredging to a potentially suitable near shore facility. No suitable near shore facility was available. Pipeline handling issues and the costs associated with processing of slurry make-up water would also be prohibitive. The one potential exception to this would be the use of the Tilcon Ringwood Quarry as a near shore location for the placement of dredged materials from the Browns Point and Belcher Creek areas.



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**Figure VI-1 – Areas of Potential Dredging**



 <p>1200 MacArthur Boulevard Mahwah, New Jersey 07430 (201) 529-5151 f:(201) 529-5728</p>	<p>Figure 2-3 Areas of Potential Dredging</p> <p>Greenwood Lake Dredging Plan Greenwood Lake Commission</p>	
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Direct transport of material to a location like the quarry would require access to a pipeline route. Safety concerns from pipe breakage in residential or other areas and the potential for lines plugging could result in down time for a contractor. This could potentially put the Commission at risk for claims from the general public or from the contractor. Placement of a pipeline from the Browns Point and Belcher Creek areas could exit the lake at the South Shore Marina and would then travel along the north side of Greenwood Lake Turnpike. A road crossing would be required at Awosting Road and also at Greenwood Lake Turnpike at Burnt Meadow Road where the pipeline would then enter the quarry. The total distance would be approximately three miles. Crossing of six private driveways or roads would also be required along the pipeline route and there is at least one significant change in elevation that would require the use of multiple booster pumps along the route. As a result, although mechanical dredging is recommended, further assessment of hydraulic dredging may be warranted if access to the quarry for the placement of material is arranged and the quantity of material would justify the mobilization costs for a hydraulic dredge and multiple booster pumps.

***“Dredging in the dry”*** was ruled out due to various concerns and challenges. For “dry dredging” to be successful, the dredging would have to commence during the winter months when the lake’s drawdown is greatest and the soft sediments would need to be frozen. There are several site conditions which make dredging in the dry difficult to contract. The bathymetry of the proposed dredging areas shows several deep holes which would make complete dewatering impossible. These areas would be unreachable by this excavation method and would remain undredged. Several dredging sites would also not be expected to be fully exposed during a drawdown and inflows from Belcher Creek would be expected to continue.

Geotechnical reinforcement fingers may also be required based on past experience and the lack of geotechnical data to accurately define substrate conditions. The process of building and removing these fingers would require large amounts of clean fill materials to be moved to the dredging area, stockpiled, moved to additional dredging areas and eventually removed to form these fingers. The additional earthwork required by this methodology could be a significant additional justified cost.

Contracting dredging operations using this method on such a large scale will also cause significant additional justified cost due to the unknown site conditions. It is difficult to provide a contractor with detailed plans and specifications when little is known of the geotechnical properties of the material to be dredged and the substrate. Additional geotechnical investigations could be completed, but may not prove to be cost effective as they cannot guarantee contractor confidence. If geotechnical reinforcement fingers were not required, the contractor would still run the risk of embedding equipment in the sediment which will ultimately lead to equipment delays (i.e. longer project duration), additional justified costs due to the potential increased risk and a higher potential for change of condition claims.

Working during the winter months with temperatures below freezing could potentially work at some locations assuming all materials are frozen and can be driven on. Predicting the temperatures during the contracting period however is not possible. This contracting approach would still pose risk to the Commission due to the assumed viability of the underlying sediments. Warm temperatures could cause materials to become mobile and driving trucks on the materials would pump sediments and liquefy them making traversing them difficult.



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### **Processing Methods**

No processing of dredged materials is proposed as part of the plan. Sediments will be mechanically dredged and placed into a scow. When the scow is full, a tug boat will take the scow to a nearby marina or other lakefront location for offloading of the dredged material. Material will be dug out of the scow and transferred to waiting dump trucks, or into roll off containers for temporary material staging. The roll offs can be loaded onto flatbed hauling trucks for transfer or the material can be dug out of the boxes and placed into trucks. This approach minimizes the on-site area requirements for handling of the material.

Based on site reconnaissance and further review of potential waterfront locations, there does not appear to be adequate space for staging or the drying of material at any of the locations considered. Use of the marinas without completely shutting them down for a season and having all boats, docks, and equipment moved would be unacceptable to marina owners. All material will need to be hauled off-site on a daily basis. If materials were allowed to dry naturally, these would need to sit for approximately one year.

Similar to the problems presented above with near shore drying cells, Geotubes would also not be a viable option. The use of Geotubes requires a significant area for storage (approximately two to five acres depending on the quantity of material dredged) and based on site reconnaissance areas of this size will not be available. The lack of storage space and the inability for filled Geotubes to fully dry during winter months when space might be available at a marina facility would also present problems for processing dredge material. As a result no material processing is recommended as part of the proposed dredging plan.

### **Staging Area**

Several staging locations are available. These include Browns Point Park and all of the major New Jersey marinas with the exception of Greenwood Small Craft Marina. Potential concerns associated with the use of marinas include seasonal issues, the need to temporarily relocate waterfront operations and issues related to truck traffic and safety. As mechanical dredging has been recommended, use of one or more marinas would need to occur during the off-season, probably October to December and/or April to May.

The South Shore Marina and Browns Point Park were selected as the primary staging/transloading locations. South Shore Marina is located close to the proposed primary dredge sites, several potential end use locations and local roads. The marina provides a location that is easy to access, has deep water launching areas, and a large area where supplies can be stored. One main concern would be how much space at the marina could be allocated to the project. This will be directly related to what season of the year the dredging can occur in. The Commission and the selected contractor would need to work with the marina owner to determine areas available for transloading operations and to determine the best time of year to begin and end the project to limit interference with ongoing marina operations. A conservative estimate is that approximately 1,000 cy of material could be removed per day. If more than 30-60,000 cy of material was to be dredged, dredging may need to occur over more than one season which could result in multiple mobilization/demobilization costs.

Browns Point Park was also identified as a potential staging/transloading site. This location is immediately adjacent to the Belcher Creek and Browns Point areas and Greenwood Lake

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Turnpike. The site would provide excellent access to the lake for the staging of equipment particularly for dredging equipment and/or the offloading of materials to trucks, although there is only an unimproved road to the waterfront. This road leads to an area of existing waterfront access where the Commission currently launches its weed harvester serving this portion of the lake.

While this location has very good access to Greenwood Lake and in particular the Browns Point and Belcher Creek areas which are a considered high priority sites for dredging, the location has several issues that would need to be considered for its use. A portion of Browns Point Park that borders Belcher Creek is mapped as freshwater wetlands by the NJDEP and as a result potential permitting issues or additional restrictions (e.g., transition area requirements) could potentially impact proposed use of the park. Use of the park would also require approval from NJDEP for the temporary use of a Green Acres site. Nevertheless the park would represent a good location for the staging and offloading of dredged materials.

### Dredged Material Management

The recommended alternative for dredged material management is direct transfer to truck with materials transported to the Tilcon Ringwood Quarry, which is shown in Figure VI-2. This approach provides the most flexibility and ability to manage materials. The quarry is located in close proximity to Greenwood Lake and the major proposed dredging locations and preliminary evaluations of the quarry indicate that it would probably have more than enough capacity for the placement of dredged materials. Potential future use of the quarry, negotiations with the present owner and other factors would need to be considered to advance the site as part of the overall dredging plan.

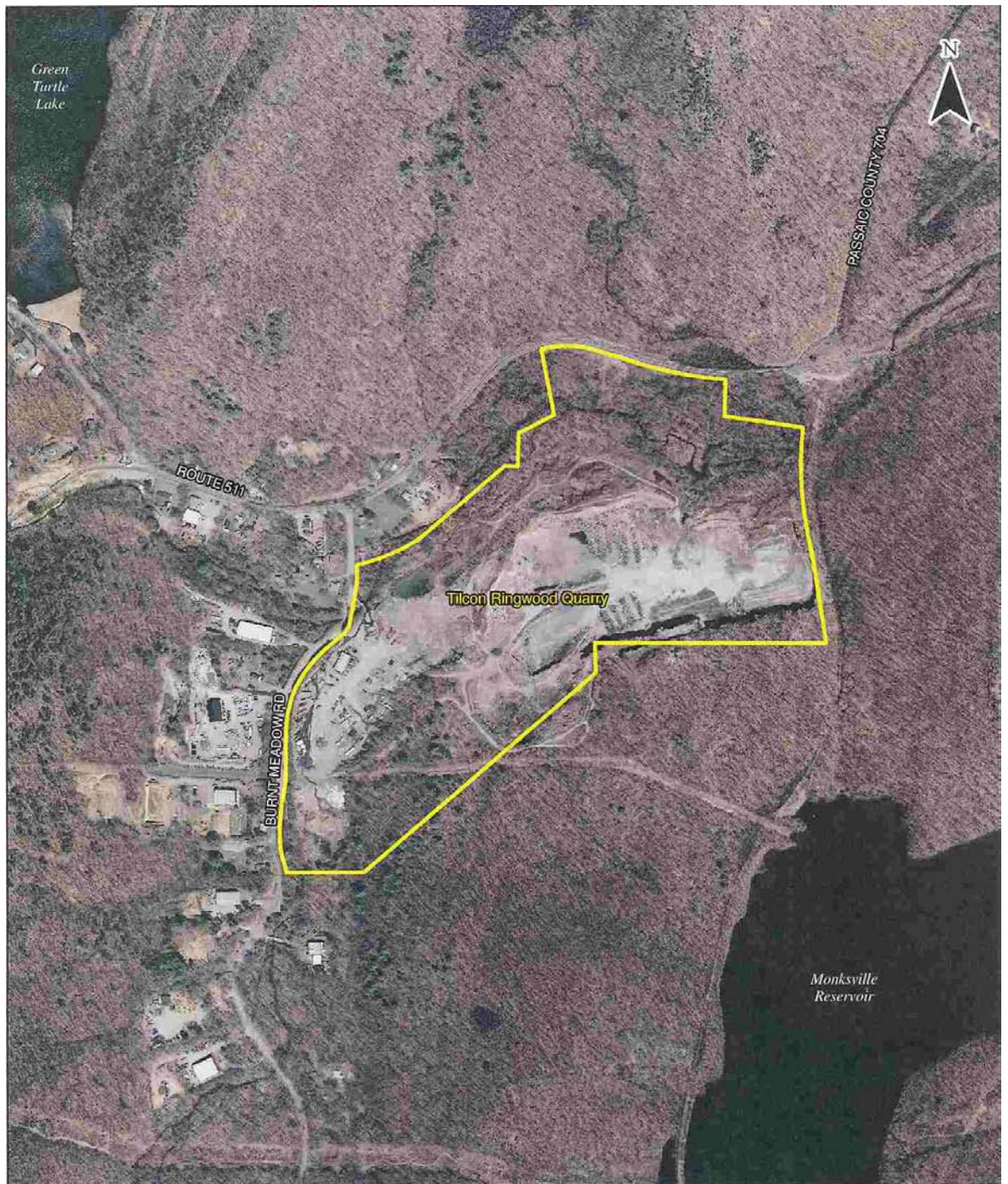
In addition to the quarry site, the Wallisch Estates site would also be a desirable location for the placement of dredged materials. Use of this site would require the development of a diked/bermed area for the placement of dredged material which may increase the overall cost of dredging. However, this site is very large and is currently under public ownership.

Other locations such as Evergreen Farms and an existing horse farm near Pinecliff Lake also have potential for the placement of dredged materials as these sites are relatively large. As with all potential end use sites, additional site-specific investigations would be required to further evaluate the utility of these locations for the placement of dredged materials. In addition, these locations are privately-owned and it is likely that both would require some level of clearing to facilitate efficient material placement.

It is also recommended that additional smaller management sites for dredged material and/or potential end users that may only require small portions of these materials be maintained as part of any dredged material management plan.



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**Figure VI-2 – Tilcon Ringwood Quarry**



Base Map Source: New Jersey Geographic Information Network, 2007  
All block and lot data is approximate.

0 262.5 525 Feet

 1200 MacArthur Boulevard Mahwah, New Jersey 07430 (201) 529-5151 f:(201) 529-5728	Figure 4-19 Tilcon Ringwood Quarry	
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### F. PLANNING LEVEL COSTS

Dredge volumes were calculated based on a dredge elevation of 608 feet NAVD88 in order to develop an accurate cost. Different scenarios were prepared to provide a range of dredging volumes and associated costs. Table VI-1 provides an estimate of the dredge removal volumes for each suggested footprint and also shows an estimate of the potential increase in water storage capacity in million gallons (MG) that would be gained as part of these efforts.

**Table VI-1. Summary of Estimated Dredge Volumes and Potential Additional Lake Storage Capacity Created**

Area	Channel Volume (CY)	Capacity Created (MG)	Mass Removal Volume (CY)	Capacity Created (MG)
Browns Point	118,000	23.86	940,000	190.07
Browns Point Subarea*			436,000	88.16
Belcher Creek	17,000	3.44		
Dam Area			14,000	2.83
Rocky Cove			30,000	6.07
Unnamed Cove			6,000	1.21
Fox Island	73,000	14.76	231,000	46.71
Storm Island	16,000	3.24	51,000	10.31
Total	224,000	45.29	1,272,000*	257.20
* Browns Point Subarea not included in total as it is included within Browns Point mass removal estimate				

Dredge volumes were based on achieving a water depth of approximately 10 feet at a normal pool elevation, which was assumed to be at the dam crest elevation. The additional water storage capacity that would be created by dredging represents a conservative estimate. This additional storage would potentially enhance the raw water that could be available to water supply reservoirs downstream of Greenwood Lake.

Costs associated with mechanical dredging, transport, offloading, and placement at the Tilcon Ringwood Quarry are summarized in Table VI-2. Only two order of magnitude cost estimates are presented within Table VI-2 for the dredging of a channel and/or mass removal for each candidate site as applicable. In addition, the dredging of a subarea of the Browns Point site is shown in Table VI-3. This location only includes approximately half of the larger Browns Point area (see Table VI-1). This subarea would only encompass a roughly triangular area that would extend from just south of Rocky Cove, to the South Shore Marina to the mouth of Belcher Creek. This area is a location of known aquatic vegetation and other issues.

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**Table VI-2. Summary of Estimated Dredging Capital Costs**

**Candidate Sites**

<b>Area</b>	<b>Channel Estimated Cost</b>	<b>Mass Removal Estimated Cost</b>
Browns Point	\$ 5,900,000	\$ 47,000,000
Belcher Creek	\$ 850,000	\$ -
Rocky Cove	\$ -	\$ 1,500,000
Unnamed Cove	\$ -	\$ 300,000
Dam Area	\$ -	\$ 700,000
Fox Island	\$ 3,650,000	\$ 11,550,000
Storm Island	\$ 800,000	\$ 2,550,000
Total	\$ 11,200,000	\$ 63,600,000

**Table VI-3. Estimated Dredge Volume and Dredging Capital Cost**

**Browns Point Subarea**

<b>Area</b>	<b>Mass Removal Volume (CY)</b>	<b>Estimated Cost</b>
Browns Point Subarea	436,000	\$ 21,800,000

Costs estimates were based on \$50/cy for mobilization, dredging, transport, placement and a minimum dredging quantity of 20,000 cy. Costs will vary based on market conditions and the size of the project(s). Costs will generally range from \$40/cy to \$55/cy (including mobilization and demobilization fees). Engineering design, construction management, permitting and sediment testing costs can be expected to range from six to eight percent of the capital costs. These costs would be in addition to the capital costs shown in Table VI-2 and Table VI-3.

Implementation of all or portions of the dredging plan could be advanced in stages if this is desirable from a budgeting or scheduling perspective. Capital costs however, would be affected if multiple mobilizations/demobilizations are required, if the Commission decides to dredge all areas or if multi-season dredging may be required for a variety of reasons.

Likewise, dependent upon the physical and chemical characteristics of the dredged material, some material may be suitable for sale as a soil amendment or similar beneficial use. The sale of this material to public or commercial users would provide a source of funds that would serve to defray the overall cost of dredging. It is however, unlikely that these funds would substantially impact the overall cost of the dredging plan.

## G. PROPOSED DREDGING PLAN SUMMARY

In summary, the proposed dredging plan for Greenwood Lake would involve the dredging of up to six initial candidate sites. Browns Point and Belcher Creek would be recommended for initial action and in particular the Browns Point subarea. These areas would meet several objectives for proposed dredging. These include the dredging of an area that is adjacent to a portion of the lake that has been shown to contribute the highest levels of phosphorus input from stormwater. In addition, dredging within this area would remove nutrient-rich sediments and would occur within



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an area known to have recurring issues with nuisance aquatic vegetation. Dredging of this area would therefore improve water quality which would be a benefit to the lake community, but also to downstream water supply reservoirs that have historically relied upon Greenwood Lake as a source of high quality raw water. These areas also represent the largest areas of dredging proposed within the New Jersey portion of the lake. This would therefore result in a potential increase of up to 193 million gallons (MG) of water storage capacity which would also represent another benefit to the Monksville and Wanaque Reservoirs. Finally, initial dredging of this area would also serve to improve navigation through an increase in water depths and the near term removal of nuisance vegetation.

It is recommended that proposed dredging be accomplished through the use of mechanical dredging. Excavators on Flexifloat platforms would be the recommended approach. Ease of access to all areas of the lake with limited impacts to existing lake uses and waterfront businesses would be the primary benefit of this approach. Dredged material would be placed in scows and then transported to a lakefront offloading area for direct transfer to trucks or roll off containers. While the use of hydraulic dredging may be possible for the Browns Point and Belcher Creek areas of the lake if a nearby placement site is identified, this is not the currently recommended approach. Likewise, dredging in the dry was also not recommended due to the significant uncertainty associated with subsurface conditions within the lake, the need for significant freezing of these sediments during lake drawdown activities which cannot be assured and the potential need and cost associated with temporary fills that may be required to make this alternative more viable. All of these represent significant risks that contractors would incorporate into their costs for the proposed work and/or would potentially expose the Commission to contractor claims.

It is recommended that dredged materials be offloaded directly to trucks or roll off containers at either the South Shore Marina and/or Browns Point Park. No processing of these materials is recommended. Both of these locations are located in immediate proximity to the largest candidate dredge locations (Browns Point and Belcher Creek) and are also closest to the two recommended dredge management locations, the Tilcon Ringwood Quarry and Wallisch Estates. Materials would be transported directly to one or both of these sites as part of the plan.

## H. FUTURE ACTIONS

Implementation of a dredging plan for Greenwood Lake would only represent one component of the overall plan for the continued improvement of water quality. The continuation of prior programs and initiatives implemented over the past 20 years by the Commission and other lake stakeholders, as well as the implementation of current and future proposed actions must be continued as part of an overall integrative management plan for the lake.

Existing programs that should be implemented, continued and/or expanded, as applicable, include the following:

- ◆ Continued weed harvesting;
- ◆ Periodic lake drawdown for weed management and maintenance activities;
- ◆ Continued wastewater treatment plant improvements;
- ◆ Storm water management and retrofit programs;
- ◆ Completion of the stump reduction program;
- ◆ Septic management plans and ordinances;

## VI. GREENWOOD LAKE DREDGING PLAN

- ◆ Ongoing and future enforcement of current and future ordinances; and
- ◆ Ongoing education and outreach programs.

The continued implementation of these programs and initiatives in conjunction with the dredging of selected portions of the lake to improve water quality, remove nutrient-rich sediment, reduce aquatic nuisance vegetation and increase overall storage capacity will continue the improvement of Greenwood Lake. Improved water quality will benefit the surrounding communities, increase the attractiveness of the lake as a destination for water-based recreation, increase economic activity within the surrounding villages and towns, and ensure that Greenwood Lake continues to represent a high quality source of raw water for downstream public water supply systems.

## VII. HIGH PRIORITY ACTIONS

### VII. HIGH PRIORITY ACTIONS

#### A. IMPLEMENTING ACTIONS

##### **Administration and Funding of the Greenwood Lake Commission**

The Greenwood Lake watershed helps to supply water to over three million residents and thousands of businesses in New Jersey. The Greenwood Lake Commission (the Commission) is a bi-state agency created in 2001 by the New Jersey and New York State Legislatures with the directive to assess threats to the lake and watershed area and develop strategies for protecting and managing the watershed to improve water quality and safety, as well as providing a better environment for swimmers and boaters. The Commission is composed of 11 volunteers appointed by the state, county, and municipal stakeholders in New Jersey and New York,.

While the Commission has accomplished several major projects since its inception, which were funded by various governmental sources, it has been seriously limited by a lack of operational funding. Though the Commission was created by state agencies, the State of New Jersey will not provide a budget for it. A partial solution to this problem is the implementation of a user fee program for boaters on Greenwood Lake. The New York State Legislature passed legislation in 2006 enabling the Commission to collect a user fee but the New Jersey State Legislature did not act until 2010. The Commission started collecting a user fee in 2010. Revenue from the user fee will help fund the Commission's administrative operations and initiatives outlined in this action plan. Funding from other sources will also be needed.

***Action:** Work to implement the user fee program so that the Commission may have sufficient funding to be able to plan and implement the high priority actions described herein.*

***Action:** Seek other sources of funding.*

#### **B. IMPROVING NATURAL RESOURCES AND RECREATION OF GREENWOOD LAKE**

The natural resources, and the economic and recreational values of Greenwood Lake are intrinsically linked. Restoring lake ecology by reducing eutrophication will improve fisheries and make the lake safer and more attractive while responsible boating practices will reduce the amount of pollution entering the lake.

##### **Weed Harvesting**

Weed harvesting is an important tool for maintaining the recreational quality and economic value of Greenwood Lake which makes the lake a major regional attraction. The Commission currently owns 3 weed harvesters but funding is required to operate the weed harvesters on a regular basis.<sup>1</sup> Income from a boat user fee will help fund the operation of the weed harvesters.

***Action:** Continue weed harvesting operations.*

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<sup>1</sup> Greenwood Lake Commission Progress Report: 2000-2006, August 2006.

## VII. HIGH PRIORITY ACTIONS

### Lake Drawdown

The most recent drawdown of Greenwood Lake was in 2006-2007 and the next one will be coordinated for the winter of 2011-2012. The drawdown is a useful lake management tool for Greenwood Lake because it can damage root growth of nuisance aquatic plants and give dock owners the opportunity to make repairs.<sup>2</sup> The drawdown also provides an opportunity to remove or cut down nuisance stumps in the southern portion of the lake.<sup>3</sup> The “Greenwood Lake Water Level Management Plan” provides guidance for the drawdown process and was updated in 2010.

**Action:** *Implement drawdowns every four or five years.*

### Stump Reduction

The 2006-2007 stump reduction program succeeded at removing over 2,000 stumps from approximately 70 acres of lakebed. However approximately 1,000 stumps could not be reduced due to a lack of funding.<sup>4</sup> Since the completion of the first phase of stump reduction, boaters have expressed positive feedback as more of the lake is now safer for boating and the water depth was increased as much as 3 feet. The stump reduction program is an important activity for the Commission because its success in 2007 demonstrates to the public and government funders that the Commission can accomplish projects that improve the safety and water quality of Greenwood Lake. This project should be completed with the next drawdown of the lake.

**Action:** *Utilize a \$90,000 federal grant to implement a stump reduction project during the next drawdown of Greenwood Lake.*

### Dredging

Benefits of dredging portions of the southern part of Greenwood Lake would be reductions in nuisance vegetation or weed growth and better nutrient control. According to the “Total Maximum Daily Load (TMDL) for Phosphorus” Report for Greenwood Lake, 41% of the lake’s total phosphorus load comes from phosphorus stored in lake sediment.<sup>5</sup> The most direct way of reducing this source of phosphorus is by dredging, which will remove some of this phosphorus laden sediment from the lake system. Other benefits of dredging could be better boating, swimming, and fishing conditions, and a safer and better environment for all users of the lake. Another benefit for millions of people in northern New Jersey would be an increase in the lake’s capacity to store clean water supplies for downstream users. As reported in the “Greenwood Lake Dredging Plan” and summarized in Section VI, the consultants, HydroQual and associates, have developed plans to dredge portions of the lake.

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<sup>2</sup> Greenwood Lake Commission Progress Report: 2000-2006, August 2006.

<sup>3</sup> Greenwood Lake Commission Stump Reduction Project: 2006-2007, March 2007.

<sup>4</sup> *Ibid.*

<sup>5</sup> New Jersey Department of Environmental Protection, Division of Watershed Management. 2004. Amendment to the Northeast Water Quality Management Plan, Total Maximum Daily Load for Phosphorus to Address Greenwood Lake in the Northeast Region. Proposed: June 7, 2004; approved: Sept. 2004.

## VII. HIGH PRIORITY ACTIONS

**Action:** *Review the dredging parameters recommended in the HydroQual study and pursue these recommendations*

The HydroQual concept plan will be used to file for the necessary permits from the State of New Jersey and the Army Corps of Engineers. The cost estimate will be used to request funding for the project. In 2010 Senator Joseph Penacchio introduced Bill #S710 “Supplemental appropriation of \$2.5 million to dredge Greenwood Lake in Passaic County” to the New Jersey Senate.

**Action:** *Obtain funding for dredging project.*

A request for proposals (RFP) should be written to solicit bids for the dredging project based on the parameters determined by the Greenwood Lake Commission. The bids must include an engineering concept plan and a cost estimate.

**Action:** *Write an RFP for dredging Greenwood Lake and solicit bids.*

While the entire dredging project could take several years to complete, it will be critical that the Commission continue to work on other phosphorus reduction activities. When coupled with other long term measures, dredging will be an important investment in the health of Greenwood Lake, and maintaining adequate water supplies for millions of residents and thousands of businesses that rely on the lake’s water in northeastern New Jersey.

**Action:** *Implement dredging project in Greenwood Lake.*

### Boat and Dock Safety Programs

Accidental oil spillage is a potential source of pollution of Greenwood Lake that can be avoided by responsible fueling techniques. Responsible fueling is explained in the “Love your boat? Love Greenwood Lake!” brochure. This brochure addresses the issue of careful boat refueling. Similar brochures could be created to address issues such as responsible angling to reduce the spread of fish diseases (“Love Your Fish . . .”), and cleaning boats from other lakes (“Love Your Boat Even More . . .”).

**Action:** *Continue distributing “Love your Boat” brochures.*

**Action:** *Seek funding from “I Boat NJ” and New York programs for educational projects.*

**Action:** *Identify other potential venues for educating boat users about responsible fueling and implement an appropriate program.*

Styrofoam billets, which are also called expanded polystyrene foam (EPS), are a potential source of litter in Greenwood Lake and can be a safety hazard if not properly cared for and maintained. Polyethylene encased EPS billets are a better alternative because they prevent the styrofoam from breaking apart and absorbing any petroleum products that may be on the surface of the lake.<sup>6</sup> There is currently no legislation prohibiting the use of EPS billets. The Commission may want to consider developing an incentive program in partnership with the towns surrounding the lakes for dock owners to use polyethylene encased billets.

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<sup>6</sup> “Buoyancy Systems.” <http://www.epsmolders.org/3-float.html>



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Greenwood Lake already contains several invasive aquatic plant species, including European water milfoil and fanwort. To reduce the possibility of other non-native plant and animal species, such as zebra mussels, being introduced to Greenwood Lake, a boat cleaning program for the lake should be considered. Many lakes across the country have implemented Clean Boats Clean Waters programs; these programs could be examined by the Commission to gather ideas for funding sources and implementation logistics.

**Action:** *Identify other lakes with successful Clean Boats Clean Waters programs and create a recommendation report and budget for implementing a similar program on Greenwood Lake.*

### Fisheries Management

Fishing is an important part of the recreational appeal of Greenwood Lake, and improving the eutrophic state of the lake should have a positive impact on the fish population. If the Commission wishes to take on a more active approach to understanding and managing the fisheries of Greenwood Lake, the Commission should investigate grant opportunities from groups like the National Fish and Wildlife Foundation. A relatively new program called the National Fish Habitat Action Plan ([www.fishhabitat.org](http://www.fishhabitat.org)) could also be a potential funding source.

**Action:** *Obtain funding and develop a fisheries management plan.*

## C. REDUCING NUTRIENT LOADINGS INTO GREENWOOD LAKE

### Storm Water Management

In West Milford, Princeton Hydro, LLC, has identified 27 high priority sites for the installation of storm water management retrofits in their Storm Water Implementation Plan for Greenwood Lake (Figure III.A-4). This project currently has funding to begin implementing these Best Management Practices (BMPs) and retrofits.

**Action:** *Work with Princeton Hydro to complete Storm Water Implementation Plan that identifies and details plan for installing storm water retrofits in West Milford.*

The Commission must ensure that the retrofit plans include directions for managing this infrastructure investment in the long term; or separate management plans should be created as the installation process is underway. Many structural BMPs are dependent on regular cleaning in order to function properly. Passaic County has made a commitment to be responsible for cleaning retrofits on county roads; this commitment should be made official in a memorandum of agreement between West Milford and Passaic County.

**Action:** *Facilitate memorandums of agreement between West Milford and Passaic County for the purpose of clarifying who is responsible for cleaning and maintaining the storm water retrofits.*

Existing storm water basins and collection systems also need to be routinely cleaned. The Commission needs to work with West Milford and Passaic County to reduce both nitrogen (N) and phosphorus (P) loadings from storm water runoff by routinely cleaning out the sediment and

## VII. HIGH PRIORITY ACTIONS

plant material that collects in storm water basins and other storm water devices. Removing these materials from storm water is critical for reducing the inputs of N and P into Greenwood Lake.

***Action:** Improve management of storm water systems.*

### **Reducing Nutrient Loadings from Septic Systems**

The Township of West Milford passed a Septic Maintenance ordinance in December 2008 which requires all septic tanks and cesspools in the town to be pumped out at least every three years. This mandatory maintenance should help to reduce septic system malfunctions that can release high levels of nitrogen, phosphorus, and bacteria into local groundwater supplies and Greenwood Lake. This ordinance is more fully discussed in Section IV (pages IV-9 et seq.). West Milford also has a 604(b) Onsite Wastewater Treatment Systems (OWTS) Grant for collecting septic data in the township. This study will hopefully yield more detailed information about the impacts septic systems in West Milford have on groundwater and Greenwood Lake. The Greenwood Lake Commission should monitor the town's progress on these programs and ensure they stay on track.

***Action:** Request that West Milford provide the Commission with status reports on the Septic Ordinance and results from the 604(b) grant.*

The West Milford Septic Maintenance ordinance also directs the West Milford Department of Health to educate owners of septic systems in the proper management and operation of them. The Commission should take this opportunity to work with the Department of Health to make sure that this education material includes an explanation on the effect malfunctioning septic systems can have on Greenwood Lake and groundwater supplies.

***Action:** Reduce discharges of nutrients from septic systems by encouraging implementation of West Milford's Septic Maintenance ordinance.*

### **Reducing Nutrient Loadings from Sewage Treatment Plants**

The Greenwood Lake TMDL does not require phosphorus load reductions from sewage treatment plants (STPs) but that does not mean the five STPs in the Belcher Creek Watershed should be ignored. The Greenwood Lake Commission should be aware of the effluent quality being discharged into the Belcher Creek Watershed in order to call attention to discharge properties that could negatively affect the lake. The Belcher Creek Watershed study report in Section V provides much useful information. The Commission should request that West Milford provide monthly copies of the Discharge Monitoring Reports (DMRs) for the five sewage treatment plants located in the Belcher Creek Watershed. The data from the DMRs should be reviewed and interpreted by a scientist for the Commission.

***Action:** Reduce discharges of nitrogen (N) and phosphorus (P), as well as raw sewage, from sewage treatment plants.*

### **Rehabilitation of Belcher Creek Watershed, including West Milford Lake**

The dam at West Milford Lake is a contentious issue for many parties, including the Greenwood Lake Commission. The NJ Bureau of Dam Safety and Flood Control has declared the dam a

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safety hazard that has to be removed, but, as described in Section IV.E, doing so may have significant environmental impacts. Repairing the dam would address both safety and environmental issues. The Commission has indicated that whatever actions are taken, they should reduce nutrient loadings, both phosphorus and nitrogen, into the waters below the dam.

**Action:** *Follow up on actions proposed for West Milford Lake, and comment thereon.*

The Belcher Creek Watershed study (Section V) indicates that the following actions should be taken.

**Action:** *Improve the capacity of wetlands in the watershed to denitrify, that is to convert nitrate in the water to nitrogen gas in the air. This is done by protecting or restoring the natural functioning of a wetland. Wetlands in the watershed are shown in Figure II.C-2. Emergent wetlands that especially need to be conserved are shown in Figure II.C-7.*

**Action:** *Clean up the debris that collects beside streams and lakes.*

**Action:** *Study and address the nutrient pollution coming into and out of Pinecliff Lake and West Milford Lake, even though this pollution is ignored in the “Total Maximum Daily Load (TMDL) for Phosphorus to Address Greenwood Lake” because most of this pollution stays in the lakes.*

**Action:** *Have West Milford promulgate a stream corridor protection ordinance.*

### Monitoring

The Greenwood Lake Commission should consider setting up a data repository for the purpose of storing not only the results of this study, but information from previous studies and other reports about Greenwood Lake. Such a repository, either in a library or in an electronic form, will be valuable for providing ease of access for future reference and research.

**Action:** *Monitor on a routine basis in the future the quality of the water leaving Pinecliff Lake and West Milford Lake, as well as that entering Greenwood Lake in order to measure progress in efforts to restore the waters of the Belcher Creek watershed and Greenwood Lake to less eutrophic conditions.*

## D. IMPROVING WATER SUPPLIES

### Conserving Water Resources

Ground water is an important part of Greenwood Lake’s hydrology because it provides the base flow for the lake’s tributaries and feeds water directly into the lake. Ground water is also the primary source of potable water in West Milford through public and private wells. Reducing water consumption through conservation practices is a critical component of protecting ground water resources.

Water conservation poses a challenge in West Milford because much of the residential water supply comes from privately owned wells which cannot be regulated. Consequently most of the water conservation in West Milford will have to focus on demand-side conservation techniques with the exception of pricing methods that reduce water usage through increased billing rates.

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Demand-side water conservation methods include installing low-flow plumbing fixtures, altering landscaping with indigenous and drought tolerant plants, using alternate water sources for irrigation, and promoting behavioral changes such as taking shorter showers.

The Greenwood Lake Commission should consider using its website as a vehicle for homeowner education in addition to potentially creating publications and holding workshops or seminars. It may be advantageous for the Commission to choose one water conservation method to focus on promoting in depth instead of a broad array of methods. Better landscaping practices could be a good place to start because the Commission could not only discuss using less water but also using less fertilizer which has an impact on the lake too. Other water friendly landscaping practices include building rain gardens and installing rain barrels which reduce runoff. Properly sited rain gardens can also improve ground water infiltration. One regulatory option, which West Milford has taken, is implementing an ordinance that restricts days and times for the watering of residential lawns for the purpose of reducing the amount of water spent on landscaping.

**Action:** *Educate the public about the importance of conserving water resources.*

### **Planning for Implementation of Highlands Regional Master Plan**

The actions of Greenwood Lake users and West Milford residents directly impact both local and regional water supplies. West Milford's ground water, the quality of Greenwood Lake, and the downstream reservoirs are intrinsically linked and the Highlands Regional Master Plan (RMP) provides guidance and planning policies that protect all of these resources. As the Township of West Milford begins the RMP conformance process, the Greenwood Lake Commission should provide comments and suggestions for the revision of Township Plans. The Commission should work to ensure that the needs of Greenwood Lake described in this Restoration Plan are adequately addressed and incorporated into the documents made as part of West Milford's conformance process.

**Action:** *Write a Memorandum of Agreement between the Highlands Council, and the Greenwood Lake Commission that gives the Commission the authority to review and recommend changes to West Milford's conformance documents.*

### **Open Space Acquisition and Preservation**

Preserving properties that contain riparian buffers as open space is the most direct way of using acquisition to protect the water quality of Greenwood Lake. Section III.C. presents some ideas on sites to preserve. The Greenwood Lake Commission should review these lists, possibly consider visiting some of the properties, and creating a wish list of properties for acquisition.

Purchasing open space for preservation is an expensive endeavor and the Commission should consider partnering with nonprofit land trust groups in addition to working with the West Milford Environmental Commission. The Commission could identify properties that have qualities that benefit Greenwood Lake and determine which land owners are interested in selling their property. Partner nonprofits could then be responsible for securing funding to purchase the property and ultimately holding title to it.

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**Action:** *Preserve additional lands with high water resource values (Figure III.C-1) as dedicated “Open Space”. As a priority, acquire and dedicate vacant land in the watersheds of Green and Cooley Brooks as well as the headwaters of Belcher Creek.*

### **Community Education**

The Greenwood Lake Commission community education and outreach program should focus on homeowner and business education, particularly on the subjects of septic system management, storm water management, and responsible boating practices.

**Action:** *Communicate to the community ways to improve the health of Greenwood Lake and the quality and quantity of ground water and surface water in West Milford.*



V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

**V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED**

**Dr. Richard R. Pardi, Department of Environmental Science, &  
Dr. Michael Sebetich, Department of Biology,  
William Paterson University, Oldham Pond Field Station  
Wayne & North Haledon, New Jersey  
(2009-2010)**

**A. DESIGN AND IMPLEMENTATION OF PROJECT**

Michael J. Sebetich, Ph.D., Department of Biology, and Richard Pardi, Ph.D., Department of Environmental Science, at William Paterson University in Wayne and North Haledon, New Jersey, in the summer of 2008 were asked to design and carry out a project to implement “Project 2” as described in section I on page I-2. This project was designed to provide additional studies needed to evaluate the impacts from nutrient sources in the Belcher Creek watershed that had not been adequately addressed before.

The goal of this project, according to Dr. Sebetich and Dr. Pardi, was “to determine if inputs of nutrients and other constituents delivered to Greenwood Lake via Belcher Creek are the probable source of nutrient and other loadings to the Lake and the primary cause of algal blooms and excessive macrophyte growth within the Lake.” The Quality Assurance Project Plan for this project was approved by the US Environmental Protection Agency in June 2009, and field work began. The principal investigators were Dr. Pardi and Dr. Sebetich. They were assisted by five students or recent graduates. Their findings, as reported by Dr. Pardi and Dr. Sebetich, are presented in this section V. *References to other sections have been added, and are in italics.*

**B. PREFACE**

No water body in an urban or even sub-urban environment can ever hope to be considered in a “state of nature.” The presence of people inevitably places some level of stress on the natural living and inorganic systems of a watershed. The response of those stressed water bodies can be minor or catastrophic depending on many factors including the extent of human impact and the nature of the natural system under stress. Some water bodies can absorb a great deal of stress with little apparent impact; others essentially collapse and lose all ability to support any designated use.

The Belcher Creek/Greenwood Lake watershed is at a crossroads in its ecological development. Depending on which path of management the watershed takes, Greenwood Lake will evolve either in the direction of typical, heavily-polluted, eutrophic bodies of water in need of constant maintenance to make them even tolerable to human uses; or, it can be led down a sustainable path toward a modest level of self-maintenance, in which all of its designated uses are supported to a significant degree.

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

### C. EXECUTIVE SUMMARY

In this monitoring study the stream was found, for the most part, rather healthy, yet clearly stressed. Fluctuations in nutrient concentrations, dissolved oxygen levels, and other water quality variables revealed a dynamic system that is, for the present, “coping” with that applied stress. However, there are clear signs, for example in the frequent occurrence of nitrogen limitation of primary productivity, that the stream could be easily “tipped” into a far less positive ecosystem status.

The fact that a substantial portion of the watershed lies within protected forests and that most of the headwaters of Belcher Creek lie within those forests has been a major factor in moderating the impact of human activities on the quality of water within the Creek and, ultimately, Greenwood Lake. Similarly, the presence of abundant wetlands within the valley, along and across the Creek’s channel have acted as “filters” to further mitigate the impact of human activities on the stream.

On the negative side, a general paucity of groundwater resources, shallow water tables, thin soils, and the widely-distributed nature of the waste-water treatment systems within the residential areas of the watershed, all combine to render Belcher Creek rather “fragile” and susceptible to the deleterious effects of human activity.

### D. INTRODUCTION

#### Watershed Background

The characteristics of the Greenwood Lake and Belcher Creek watersheds are treated in detail elsewhere in this report. Noted here briefly are those characteristics of that watershed which are most critical in controlling water quality and habitat within Belcher Creek, the primary focus of the monitoring survey conducted during the spring and summer of 2009.

The monitoring survey detailed here was conducted within the Belcher Creek watershed, which is the primary tributary to Greenwood Lake. The Belcher Creek watershed lies entirely within the Township of West Milford in the state of New Jersey. Overall, the Belcher Creek watershed is elongated south to north with the main channel of the creek following the central axis of a narrow valley leading north to Greenwood Lake. Much of the western half of the creek’s watershed is protected by New Jersey State forests. (*Figure I-5 shows major state parklands within the watershed.*) Residential portions of the watershed are primarily in the lowest areas of the valley (*Figure I-3*).

#### Physical Setting: Geology, Hydrology, Soils and Climate

The Belcher Creek watershed lies within the Highlands Physiographic Province of New Jersey. The bedrock of the watershed consists almost entirely of pre-Cambrian metamorphic rocks. There are outcrops of lower Paleozoic meta-sedimentary rocks, such as the Greenpond conglomerate, which lie atop the underlying pre-Cambrian basement. These lower Paleozoic meta-sedimentary rocks are found on the western ridge (Bearfort Mountain) bordering the Belcher Creek/Greenwood Lake valley. There are no Mesozoic or Cenozoic rocks in the area with the exception of generally thin, unconsolidated Pleistocene (ice age) surficial sediments

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

deposited in the last few million years. The structural trends (axes of folding) of both the underlying pre-Cambrian and early Paleozoic rocks are approximately NNE to SSW more or less controlling the major elements of the areas relatively high-relief geomorphology.

Stream flow drainage follows a rough “trellis” pattern. Headwaters of Belcher Creek are primarily in ponds and wetlands at elevation in parallel north-south trending valleys. These headwaters in general flow in the same or exactly opposite direction of the main channel of Belcher Creek for some distance before taking an abrupt “dog-leg”, east-west trending channel down-slope to the valley and the main Belcher Creek channel.

As noted, surficial Pleistocene deposits within this watershed are primarily thin. They are mostly glacial tills that were deposited as ground and lateral moraines along the bottom and sides of the valley by continental glaciers that flowed roughly from north to south closely following the underlying structural trends of the bedrock. These tills are clayey, poorly sorted sediments, which are, for the most part, poor aquifers. Similarly, the metamorphic bedrocks are not good aquifers, although some evidence (as noted below) exists for areas of significant groundwater flow. Although there is enough groundwater resource for some domestic supply, for most of the watershed, stream flow is fed by run-off with a minor component of base (groundwater fed) flow. This means that Belcher Creek, even in the absence of human interference in the form of paved, impervious surfaces, will exhibit a strongly “flashy” discharge – rapid increase in flow rate during storm events followed by rapid decrease after storms abate.

Soils of the eastern half of the watershed consist of the Swartswood-Norwich-Wurtsboro association, while those of the elevated western half of the watershed are of the Swartswood-Rock outcrop association (Seglin, 1975). These soils are thin, gravelly and generally acid soils of low inherent fertility and water capacity. As noted by Seglin (1975), “The slowly permeable fragipan severely limits the use of the soils for septic effluent fields.”

Besides the relatively “flashy” character of the stream’s flow, another characteristic of the watershed that is a consequence of the underlying, shallow, tight bedrocks and high-relief, is the presence of many wetland areas and natural ponds. Many of these ponds and wetlands have been modified by the construction of dams which range in size from less than a meter to the large dam which impounds the water of Pinecliff Lake. These abundant wetlands, ponds and impoundments lying near or across stream channels, are what sustain and regulate most of the Creek’s perennial flow. They are also a source of natural “filtration” and water “conditioning” trapping particulate matter and modifying stream chemistry before runoff waters enter the main channel.

In the upper portions of Belcher Creek and its tributaries the streams are very shallow and its beds are largely boulders and cobbles. After Belcher Creek passes through Pinecliff Lake and then downstream of the dam on that lake to Greenwood Lake the stream bottom is silty and deep (> about 2 m).

The climate of the area is humid, temperate and continental with annual precipitation in the range of 120 to 137 cm (47 to 54 inches) occurring mostly in July and August. It needs to be noted here that the spring and summer of 2009 were extremely wet, not so much due to the quantity of precipitation, which was only slightly above normal, but due to the frequency of precipitation events (Figure A54 on page V-77). Throughout the sampling period all segments of Belcher Creek and its tributaries were flowing continuously even though there were significant variations in that flow.

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

*The geology, hydrology, soils and climate of the watershed are also described in Sections II.A and II.B. Section II.D discusses Water Resources. Of particular concern should be the findings in Table II.D-4 regarding the availability of ground water in the Belcher Creek watershed.*

### **Land Use & Utilities**

As noted earlier, most of the western half and some portions of the eastern edge of the elongate Belcher Creek watershed are forested land with almost no human influence. Residential and commercial land uses are confined almost entirely to the valley bottom. At that, most of the commercial areas are in the northern portion of the Belcher Creek valley just before the creek enters Greenwood Lake, while the southern (higher) portion of the watershed is low to moderate density, residential land use. Recent, intensive commercial development of the northern portion of the Belcher Creek watershed has led to marked increases in impervious surfaces, primarily in the form of parking lots and large, flat-roofed buildings. (See Figure I-3.)

A unique aspect of the Belcher Creek watershed lies with the system of waste-water disposal. Much of the residential and some minor commercial waste water disposal were historically via septic systems, i.e. via groundwater. Over the past several decades, many of the homes and most new commercial establishments have been sewerred. There is, however, no central sewer system. Rather, there are several municipal waste water treatment plants that vary greatly in capacity. A number of these plants discharge directly into either the main channel or tributary channels of Belcher Creek. Hence, rather than having to deal with a single source of waste-water discharge at one specific point in the stream's channel, waste water effects are widely distributed both geographically and in the quantity and quality of impact on water quality and habitat.

Agricultural land use within the watershed is minor. Stables and other equestrian establishments are the primary agricultural land use types and occupy a very small area within the watershed. There are virtually no areas of industrial land use other than marina operations.

### **Summary of Previous Studies**

Prior sections of this report (*Section III*) have detailed the results of several other previous studies that have been conducted on the waters of Belcher Creek and Greenwood Lake. Comments here compare aspects of those studies with results from the monitoring effort reported on here. These comparisons are done for three separate areas of results:

1. Nutrient Studies
2. Macroinvertebrate Habitat Analyses
3. Bacteriological Studies

#### **Nutrient Studies:**

Analyses conducted by the US Environmental Protection Agency in 1976 and Princeton Aqua Science in 1983 had established that the primary cause of the observed eutrophication of Greenwood Lake was an increase in nitrogen and phosphorus levels in the waters of the Lake and its primary tributary, Belcher Creek. The 1983 study by Princeton Aqua Sciences came to the conclusion that phosphorus was the primary limiting nutrient (with occasional instances of nitrogen limitation) and that the largest source of phosphorus was recycling within the Lake from bottom sediments. They further concluded that non-point sources such as runoff were the next most important source of phosphorus with malfunctioning septic fields, precipitation and

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municipal waste-water treatment plants contributing relatively minor amounts of nutrients to the Lake. Recommended improvements in waste-water treatment, however, were likely the primary reason for water-quality improvement noted in the NY State 1989 Clean Lake Report and the US Army Corps' Clean Lake Study of 1989. It seems likely, therefore, that even though waste-water treatment plants and septic fields may have smaller gross impacts on nutrient concentrations in the Lake and stream, the incremental addition of nutrients by these sources has a far greater impact on water quality.

### **Macroinvertebrate Habitat Analyses:**

Allied Biological conducted several studies of macroinvertebrate habitat in Belcher Creek from 1998 to 2005 (Allied Biological, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005). Their results were very similar to those reported on here.

### **Bacteriological Studies:**

Princeton Aqua Sciences' 1983 study of Belcher Creek water found very high levels of bacteria clearly associated with faulty waste-water treatment plants, especially the Birch Hill plant. Subsequent studies done after improvements were made to that and other waste-water plants and regular monitoring, such as conducted on the waters of Pinecliff Lake, have found levels that are much lower than noted in 1983, but, still, in many cases above the acceptable limits for designated use.

## **Project Goals, Objectives and Limitations**

The primary goals of this monitoring project were to assess water and habitat quality within the Belcher Creek watershed during the spring and summer of 2009. Particular concerns were quantifying the human impacts on the Creek's waters and the identification of any specific and significant sources of water pollution, especially nutrients. The work was carried out between June and September of 2009. A few measurements were made before and after that period as noted in the discussion below.

## **E. METHODS**

### **Survey**

During the conduct of this study several different means were used for collecting survey data about various characteristics of the watershed. Topographic maps and aerial photographs available from New Jersey internet web sites and national databases such as Google and the US National Resources Conservation Service (NRCS) soil web site were used regularly to locate sites for potential sampling. Often stream-channel neighbors were asked for any input on human impacts on the stream. In addition to the Passaic River Coalition, the Pinecliff Lake Association, through Dr. Doris Aaronson, provided data on water quality surveys of Pinecliff Lake.

### **Weather**

Values for precipitation used below in the discussion of stream discharge were obtained from public data sets of the US National Oceanographic and Atmospheric Administration (NOAA) for the weather station in nearby Ramsey. Comparison with the Charlotteberg weather station data,

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which were incomplete, shows that the Ramsey numbers are fairly valid for the whole area. A histogram of precipitation for the period of monitoring follows in Figure A54 on page V-77.

### Hydrology

Discharge measurements were made by standard US Geological Survey (USGS) profile/velocity techniques (USGS, TWRI, 2003, Book 4). Most velocity measurements were made using a Swoffer rotating propeller meter. Occasionally a Swoffer-modified USGS rotating bucket meter was used to measure velocity. The two units have been calibrated against each other and are identical within the limits of measurement. The measurements were all made by stretching a tape measure line perpendicular across the stream and measuring the depth and velocity of the stream at several points along that line. The stream profiles are generated from the distance/depth data. Discharge measurement results for some specific days are shown on schematic maps of the watershed in Figures AS7 through AS15 (pages V-30 to V-38). It can be seen from some repeat measurements on the same day and time that the errors can be considerable, especially at very low flow rates. However, overall the measurements appear to make sense in terms of measured discharge relative to basin area.

### Water Quality

#### Field Measurements:

Some water quality variables can only (or preferentially) be determined *in situ*. Three complimentary types of field measurements were made on Belcher Creek water in the field:

1. Discrete measurements of turbidity, temperature, conductivity, dissolved oxygen and pH at specific sampling points.
2. Continuous measurements of temperature, conductivity, dissolved oxygen and pH at regular intervals over several days at specific sampling points using a data-logging sonde.
3. Measurements of optically-active dissolved organic materials measured at specific sampling points by means of a field spectrometer.

#### Discrete Measurements:

Several different field instruments were used to monitor water parameters in the field. A YSI multi-parameter meter Model 556 was regularly used to measure temperature, conductivity (and specific conductance), dissolved oxygen (mg/L and % saturation), and pH. Temperature measurements were verified via a NIST-traceable digital thermometer. Dissolved oxygen measurements made with the YSI 556 model were regularly checked against a YSI 55 dissolved oxygen/temperature meter. In general the dissolved oxygen measurements made by the dedicated YSI 55 meter were more accurate than those made by the YSI 556. A “pen” type pH meter was sometimes used to check field pH measurements made with the YSI 556 meter. Turbidity was measured using a LaMotte field turbidity meter. This meter has been regularly calibrated against a Turner Model II laboratory turbidity meter and against several standards of different values.

#### Continuous Measurements:

The YSI 6920 sonde was deployed four times at different sites during the summer:

- June 17-23 - Morestown Brook at farm along Lincoln Avenue - downstream from the Birch Hill Sewage Treatment Plant (STP) (Figure A45);

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- June 24-July 10 - headwaters at Crescent Park just downstream from STP (Figure A46);
- July 15-23 - Stowaway Road above entry of Belcher Creek into Pinecliff Lake (Figure A47);
- August 11-27- Coyote Cove - downstream from Olde Milford STP (Figure A48).

The YSI 6920 sonde is a stand-alone, battery-operated device (approximately 50 cm long and 10 cm in diameter) that is placed in the stream usually resting on the bottom and tethered to a tree or other permanent feature so that it remains hidden, submerged and in place. The duration of deployments was about 1 or 2 weeks - limited by battery life. The device measures temperature, conductivity (and calculated specific conductance), dissolved oxygen (calculated % saturation and mg/L), pH, and water depth. Measurements are made every 30 minutes. The water depth is not reliable in shallow waters such as Belcher Creek since depth is determined from a pressure sensor on one side of the sonde and the sonde may rotate. The device is sensitive and delicate, especially the oxygen sensor. YSI oxygen sensors use a semi-permeable membrane in this case held on by an "O"-ring. That configuration is prone to slipping off, being punctured or gumming up. All three happened during deployment on Belcher Creek, so that much of the DO data is unreliable. However, much can be gleaned from the data sets, especially water quality variations at night and during storm events.

### **Fluorometry:**

The fluorometric measurements were made using a Turner 10 AU portable fluorometric spectrometer. The unit measures fluorescence in the sample by exciting the sample with UV light. The sample flows through the measurement cell using a pump with one end submerged in the stream near the bottom. The most common fluorescent chemicals present in water are optical brighteners found in detergents. Hence these measurements can indicate discharges of sewage into a water body. Optical brighteners are not considered toxic in and of themselves because the concentrations measured are in the parts per trillion. As far as we know, nobody has done any eco-toxicological studies on these ubiquitous chemicals. They also decay with time if exposed to sunlight; however, that is a very long time, probably years or decades.

### **Major Element Laboratory Chemical Analyses:**

Laboratory chemical analyses of the samples were conducted in three stages. The concentration of major elements was measured using ion-chromatography. Alkalinity was measured using a Mettler automatic titrator. Phosphorus (P) concentrations were measured by spectrophotometric means. The major chemical analyses are summarized in one large "Tri-linear" or Piper diagram which is presented in Figure A53.

Samples were collected in the field by immersion of clean, virgin polyethylene bottles directly into the stream flow where possible. A few samples were obtained using a 4.2 liter, acrylic, horizontal Van Dorn sampling device (Wildlife Supplies, 1940-C62) which was let down into the stream from overpasses and which captures approximately 2 liters of water at a time. From that sampler water was transferred to polyethylene bottles.

Two sets of samples were collected for analyses by Integrated Analytical Laboratories (IAL) and by William Paterson University (WPU). Aliquots (generally 125 or 250 mL) of samples were filtered in the field and stored under ice in the field or under refrigeration in the laboratory. Unfiltered samples were used for total phosphorus (P) and Kjeldahl nitrogen (N). All laboratory analyses followed standard methods as detailed in the project Quality Assurance Project Plan.

The goals in doing these extensive chemical analyses were:



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1. To obtain the nitrogen species concentrations for input into the nutrient file. The ion-chromatograph used in the chemical analyses is not very sensitive to phosphorus; hence, those analyses were performed using a spectrophotometer. Although ammonium ion was detected in many samples, and that presence may be significant, the levels could not influence the overall ratio of nitrogen to phosphorus (N/P) concentrations and were not included in the nutrient file.
2. To follow watershed trends in major element concentrations which might reveal patterns of chemical and physical processes in Belcher Creek.
3. To provide a check on overall analytical accuracy by doing a charge balance on the combined cation and anion results. In general, charge balance near +/-5% was achieved, but analyses on very dilute and very concentrated samples had larger errors.

Most major element chemical analyses were performed using a DIONEX DX120 Ion-chromatograph. Aliquots of the filtered samples were injected into the instrument (separate runs for cations and anions) along with a series of standards. The peak areas for the standards with known anionic and cationic concentrations were used to develop calibration curves which were then used to obtain concentration values for the unknown samples. Results are expressed as either ppm (mg/L, milligrams per liter), ppb (ug/L, micro-grams per liter), or meq/L (milli-equivalents of charge per liter).

Alkalinity was measured on approximately 40 mL (exact sample volumes were determined by weight) aliquots of un-filtered samples using a Mettler auto-titrator. Alkalinity as reported by this instrument is in units of mg/L as  $\text{CaCO}_3$ . Within the range of pH found in nearly all samples of Belcher Creek water, alkalinity can be easily converted to bicarbonate ( $\text{HCO}_3^-$ ) ion concentration by multiplying alkalinity by 1.02. The value for bicarbonate so obtained was then used, along with pH, to calculate the concentration of carbonate ion. The bicarbonate and carbonate ion concentrations entered into the calculation of ionic balance for overall stream major-element chemistry and for plotting on the Tri-linear diagram as discussed in the Results section.

### **Tri-Linear – Piper Diagram:**

The tri-linear or Piper diagram is a graphical method developed by hydro-geologists to visually summarize major-element, dissolved ionic chemical analyses of natural waters. The diagram is generated from complete anionic and cationic chemical analyses of water samples. The measured concentrations of anions and cations (usually reported as mg/L or  $\mu\text{g/L}$ , ppm or ppb) are first converted to charge equivalents (meq/L or  $\mu\text{eq/L}$ ). This conversion to equivalents places all dissolved ions on a charge-equal basis; different weight concentrations of various ions may have the same charge concentration (e.g.,  $\text{Cl}^-$  vs.  $\text{SO}_4^{2-}$ ). Then, the equivalent values are normalized among samples by conversion to percentage (%). By converting to percentage of total anions and cations, the effect on species concentration of evaporation or addition of water is removed; i.e., if nothing other than water is added or removed from a water body, all analyses would plot as a single point on the Tri-linear diagram.

Each set of anion and cation analyses from a particular sample are plotted as points (usually with some distinctive color or symbology) on a specialized figure (Figure AS53) which consists of two triangular diagrams below a diamond-shaped diagram. The two triangular diagrams correspond to cation analyses (left) and anions analyses (right). The diamond shape portion of the figure, above and between the triangles, summarizes both anions and cations with data points

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projected onto it from the separate triangles below. Each set of axis are labeled from 0 to 100% and identified as to ionic specie or species. The diagram plots only the major expected ions. Major expected anions are chloride, bi-carbonate, carbonate, and sulfate. Major cations are sodium, potassium, calcium and magnesium. These can be expected to be the major ions in most ground and surface waters.

This type of diagram is useful for evaluating the following hydro-geo-chemical scenarios:

1. Mixing of two or more water bodies;
2. Physical addition (rarely subtraction) of ionic species as dry materials;
3. Addition or removal of ionic species due to chemical reactions within the water body;
4. Type classification of waters.

Sample results that fall in the same area of each section of the figure can be interpreted as having the same origin and differing only due to the addition or evaporation of water. Clusters of points indicate multiple origins. Samples that fall along a linear trend indicate addition by solution of dry materials or simple mixing of distinctive water bodies. Curvilinear trends may point to chemical reactions within the water body.

### **Nutrient Analyses:**

Samples analyzed by IAL for nitrogen (N) and phosphorus (P) were done using an auto-analyzer. Samples analyzed by WPU were done using either the DIONEX ion-chromatograph (nitrate & ammonia) or UV/vis spectrophotometer using standard methods for P analysis. The sensitivity of both WPU methods is far better than IAL's, hence, WPU was able to obtain measureable results for all but one sample, while many samples from IAL are reported as "ND" or below detection limits. Although WPU made some attempts to analyze "Kjeldahl" N (total N), these analyses were performed solely by IAL. Otherwise, P analyses performed by the two labs are very comparable.

## **Biological and Habitat Analyses**

### **Bacteriological Analyses:**

In all cases samples were obtained in the field using sterile 125 mL standard, polyethylene bacteriological sample bottles (Cole-Parmer WU-66360-00 or equivalent). Two sample bottles from each site were delivered to Integrated Analytical Laboratories (IAL), while one other bottle was retained for analysis by William Paterson University (WPU), for a total of three bottles from each site for each sampling series. The samples were stored in the field immediately in ice chests and kept there until removed in the laboratory for analyses. All analyses were initiated within 6 hours of collecting the earliest sample. Results are uniformly reported as colony forming units (cfu) per 100 mL. Samples were incubated for between 24 and 48 hours, after which colonies were counted by eye. Most often sample volumes were 10 mL, so that actual plate colony counts were then multiplied by 10.

There are three different types of analysis performed among the two laboratories:

1. WPU prepared one aliquot of each sample for total coliform analysis. This class of bacteria includes fecal coliform bacteria, but also some other soil and water bacteria that are also coliforms. The counts are therefore, the highest of the three types.
2. IAL reported one aliquot of each sample for fecal coliform analysis. This class of analysis represents all coliform bacteria whose origin is considered to be the gut of warm-blooded animals. That includes humans, but also mammal and avian wildlife.

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- Both WPU and IAL performed Escherichia coli (*E. coli*) analysis. These bacteria are considered to most closely reflect the influence of human waste. However, a wildlife origin is not completely excluded. Two surveys were made by WPU alone during June 2009, and then three dual analytical sets were done by both WPU and IAL on July 1, July 15 and August 27.

### **BOD:**

Seventeen measurements of 5-Day Biochemical Oxygen Demand (BOD<sub>5</sub>) were made over the summer at 16 different Belcher Creek sites. As the name implies BOD<sub>5</sub> is a measure of the rate of consumption of oxygen in a water sample due to respiration over a period of 5 days. The procedure is very simple. About 250 mL of the sample is placed in a black, airtight bottle which contains an oxygen probe and stirrer. Four samples were run at a time in the WPU laboratory. The four bottles sit in a water bath which holds the temperature of the samples close to 20°C. Although it is only necessary to measure the oxygen level of the sample at the start and then after 120 hours, it was measured at daily intervals and then an exponential regression on the data was performed to determine the predicted value at 120 hours. BOD<sub>5</sub> will reflect the quantity of substances in the water capable of consuming oxygen. These could be inorganic chemicals, but most commonly BOD<sub>5</sub> is a measure of dissolved organic matter. As the heterotrophic organisms in the black bottle eat the organics, they lower the dissolved oxygen (DO). BOD is a required variable measured at the outflow of all sewage treatment plants, where it is usually fairly high.

### **Macroinvertebrates & Habitat:**

Macroinvertebrates are indicators of stream water quality. These aquatic organisms include larval insects, snails, crustaceans (amphipods, isopods, and crayfish), leeches, flatworms, and freshwater clams and mussels. Researchers have determined that selected taxa (species, families and orders) are sensitive to pollution, whereas other taxa are more tolerant of pollution. By identifying and counting the numbers and kinds of macroinvertebrates living in streams of various levels of water quality, researchers have developed indices that relate to water quality. Macroinvertebrate samples from 10 different sites were analyzed by Water's Edge, Baraboo, Wisconsin.

## **Field Sampling Sites**

Field sampling sites are described below. Their locations are depicted in Figure A-1 on page V-23.

BCGL1 was located near the headwaters of Belcher Creek at the intersection of Shepherds Road and Hunterdon Place. The sampling site is shaded by shrubs and trees in summer and is adjacent to a private residence on Bergen Drive. The only evident potential impacts on water quality above this location are the horse stables and private summer camp along Shepherds Road.

BCGL1a was located about five meters downstream of a culvert under a local street and downstream of Crescent Park Sewage Treatment Plant (STP) located just upstream of the culvert. Private residences bordered both sides of this sampling site.

BCGL2 at the intersection of Stowaway Road was located between an old, partially broken concrete dam and the Stowaway bridge that crossed Belcher Creek just as it entered Pinecliff Lake. Here the stream has been channelized between the old dam and the bridge. The old dam was probably constructed many years ago to create a pond which has since filled in with

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sediment and aquatic vegetation. This wetland is part of the Stanford Tract, a 200+ acre site, which is in the process of being purchased by the Passaic River Coalition for open space.

BCGL2a was a sampling site located on Belcher Creek at a culvert beneath Dockerty Hollow Road. It was upstream of the wetland that delivered water to Pinecliff Lake. Relatively dense vegetation grew on both sides of the Creek providing summer shade and plant buffer to the stream. Both water samples and macroinvertebrate samples were taken.

BCGL2b was located on a tributary stream near the old Coyote Cove bar and restaurant. The sampling site was in the wooded section upstream of the Coyote Cove complex. It was well shaded in summer, and this reach of stream had a series of small pools and riffles. This section of stream flowed through mature forest, went past a paint ball recreation area, and then entered a small wetland before crossing Union Valley Road towards Belcher Creek. Water samples were taken at this site.

BCGL2c was in a tributary upstream of Olde Milford STP at Camelot Lane. The tributary reach was bordered by mature trees and a steep rock outcrop on the southeast side. Thus this section of the stream was shaded in summer. Stormwater discharge pipes emptied into the tributary which seemed to create small sand/sediment bars in the stream, but it was relatively undisturbed in this area of small pools and riffles. Small fish were observed in one of the pools.

BCGL2d was located just downstream of Olde Milford STP at Camelot Lane. The STP discharges into the tributary upstream of this sampling site. This section of the unnamed stream skirted a relatively large wetland that was apparently created by beavers, just downstream from the STP.

BCGL3 was at the outflow of Pinecliff Lake. Water samples were taken at the culvert that traversed beneath Union Valley Road, and macroinvertebrate samples were taken just downstream of the overflow from the Pinecliff Lake dam. At this location Belcher Creek was relatively wide as it is borne from the overflow from the wide concrete dam. Thus it was open to sun insolation at all times. Aquatic plants grew along the edges of the stream and encroached into the shallow sediments of the stream, and created its own tiny wetland. This section of Belcher Creek was a favorite location for wading birds and human anglers who fished from the shoreline and from the culvert bridge on Union Valley Road.

BCGL3a was located on Pinecliff Lake, on the west shore towards the north end of the lake. Water samples were taken from the unnamed stream about 100 m before it entered Pinecliff Lake.

BCGL4 sampling site was on a reach of Morsetown Brook that extended from Lincoln Avenue downstream for approximately 100 meters through an old field area (old farmstead) that has been left fallow, and was developing into the next stage of ecological succession. Along this reach the stream was bordered by tall perennial plants and shrubs as it flowed in a northerly direction where it intersected with Belcher Creek between Pinecliff Lake and Greenwood Lake. BCGL4 was approximately 30 m upstream of Birch Hill STP plant near the vicinity of the Christian Life Center. Morestown Brook flows from Carpi Lake. This section of the brook flows past a small residential development, but the sampling site was in a wooded area with a series of small pools and riffles. Macroinvertebrate samples were taken in the old field section of the stream, and

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water samples were taken from the culvert at Lincoln Avenue. Water flow in Morsetown Brook appeared to be great enough to be able to support populations of small fish as well as macroinvertebrates.

BCGL4a was located on the outflow stream from West Milford Lake just upstream of Marshall Hill Road bridge. The stream water was turbid, indicating possible organic pollution. The sampling site was adjacent to a parking lot at a small strip mall that had a consignment shop. Thus this section of stream flowed through a fairly developed area with little natural vegetation and not much plant buffer along the shoreline. Water samples and macroinvertebrate samples were taken.

BCGL4b was a sampling site on the inflow to West Milford Lake.

BCGL5 was a lake-like section of Belcher Creek located at the Green Brook Property Owners Association Marina. Planktonic algae were sometimes concentrated on the water surface near the shoreline of the marina parking lot. Here the creek was wide and too deep to walk through. The bottom sediment was most likely muddy and soft. The low stream velocity and high exposure to sunlight contributed to the excessive growth of algae in this section of Belcher Creek. Water samples were taken here, but not macroinvertebrate samples.

BCGL5a was just downstream of the intersection of Cooley Brook and Green Brook, upstream of the intersection with Belcher Creek. The back of the A&P store was approximately 50 m from this site, and the stream had the familiar shopping cart, rubber tire, lumber, and construction debris in it. Both water samples and macroinvertebrate samples were taken there.

BCGL5b was located on Green Brook where both water and macroinvertebrate samples were taken. This is one of the few locations along Green Brook above the Valley where the stream flows above ground. For the most part, between West Lake and Waldwick Turnpike, Green Brook flows through wetlands and underground among boulder fields.

BCGL5c was located on Cooley Brook near municipal baseball fields. Cooley Brook flows to this location out of Hewitt State Forest from Surprise Lake.

BCGL5d and e are located upstream of BCGL5c on Cooley Brook within Hewitt State Forest.

BCGL6 was at the mouth of Belcher Creek as it entered Greenwood Lake at the Greenwood Lake Condominium Marina. This sampling site had the quality of a lake, wide and filled with sediment, and exposed to sunlight. Algal blooms were always evident along the shoreline adjacent to the condominium parking lot. Water samples were taken, but not macroinvertebrates.

## F. RESULTS

All results are listed in separate analytical files which are contained on a CDROM in MS Excel format. Many of the results are contained in the Figures within this document on pages V-24 to V-76.

### Hydrology

The most remarkable observation to come from the measured stream flow data is the larger than expected flow (based on basin area and known precipitation) from Green and Cooley Brooks

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

(northwest (NW) tributaries). These two streams must be receiving considerable groundwater flow. This is an important observation since this flow enters Belcher Creek just before it enters Greenwood Lake. The water in these NW tributaries is very high quality, at least down to the point where it passes behind the A&P shopping center. That flow is significantly diluting Belcher Creek in a positive way. Figures AS7 to AS15 summarize flow measurements on several different days.

### Water Quality

#### Field Measurements:

The results of field variable measurements are presented in Figures AS16 to AS20

#### Chemical Water Quality:

The results of some of the chemical analyses are shown in Figures AS23 to AS38 as concentrations at specific points displayed on schematic maps of the watershed, and in Figures AP39 to AP44, which show the concentrations of specific ions at points (measured as distance upstream from Greenwood Lake in kilometers) along the main channel of Belcher Creek.

#### Tri-Linear Diagram:

The data for 58 separate, complete elemental analyses for Belcher Creek/Greenwood Lake water samples collected between February and September 2009 are plotted on the diagram, Figure A53. Samples collected on different dates and at different sites were given different colors and/or symbols in Figure A53. The results indicate the following:

1. Since the major cation in precipitation is usually  $H^+$ , the linear trend of cations within the watershed's samples suggests that the initial solution of roughly equal ionic concentrations of  $Na^+$ ,  $K^+$ ,  $Ca^{++}$  and  $Mg^{++}$ , are modified with time and passage along the stream channel by the simple addition of  $Na^+$  and  $K^+$  – most likely simply  $Na^+$  from solution of road salt.
2. On the anion side, there is a fairly linear trend clearly driven by addition of  $Cl^-$  ion to the bicarbonate-dominated rainfall. There is some suggestion in the data, which is extremely low in  $SO_4^{--}$ , that what little sulfate is in these waters may be significantly reduced and lost during the passage downstream. This reduction, likely to  $H_2S$ , may be occurring in the abundant wetlands throughout the watershed.
3. There are no strong time dependent trends in the chemistry.
4. The samples that do not cluster toward the center of the summary diamond figure are either very clean, low-human-impact tributaries such as Green Brook, or, on the other extreme, samples taken just below STP outfalls, as well as the outflow of West Milford Lake.

#### Nutrient Analyses:

Phosphorus (P) and nitrogen (N) results are presented in a series of schematic maps which present the results from three different watershed-wide sampling events with joint analyses performed by IAL and WPU. Other results conducted by WPU only are included on a CDROM, which may be obtained upon request from the Passaic River Coalition.

Overall, dissolved inorganic (ortho) phosphate levels were approximately 50% of the total phosphate present in the stream water, except near the STP outflows where nearly all phosphorus was present in a dissolved inorganic form. These results are consistent with what would be expected for a small, turbulent, moderately impacted stream such as Belcher Creek (Allan, 1995). Phosphorus concentrations tended to decrease going downstream indicating upstream

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sources (Figures AP39 to AP46). In many cases upstream values exceeded EPA recommended standards with concentrations in excess of 40 µg/L. However, at Greenwood Lake, phosphorus values were near or below the recommended value on most sampling days.

A similar pattern exists for nitrogen in stream water. Dissolved inorganic nitrogen (DIN), almost all of which was in the oxidized nitrate ( $\text{NO}_3^-$ ) form, averaged around 10 to 20% of total nitrogen. Nitrogen concentrations were relatively low except for stations BCGL1 and BCGL1a. The high values at these stations likely reflect a combination of sources including agricultural activity just upstream (horse stables and corals) and the small STP just upstream from BCGL1a.

Nitrogen and phosphorus (and sometimes silicon) are the primary limiting nutrients in aquatic systems (Lee, Rast & Jones, 1978 & 2002). “Limiting” implies that the concentration of that element in water is the key control over biological productivity. In most natural systems, P alone is the limiting nutrient. In some impacted systems (Belcher Creek apparently among them) N and/or both N and P may be limiting. Where one or both elements are limiting, their addition to the water column increases productivity.

The relative concentrations of N and P in samples collected on July 1, 15 and August 27, 2009 are presented in a single schematic, Figure AS38. The ratio of N to P in most aquatic organisms (the Redfield ratio) is about 16:1 (Redfield, et al., 1953). Values below 16:1 in water indicate a lack of N relative to P and values above 16:1 point to P limitation. Figure AS38 indicates where either N or P or both N & P are the limiting nutrients. It can be seen that there is no strong pattern to the results for these nutrients, except that N-limitation appears to be more frequent in the central (most heavily populated and, presumably, impacted) portion of the watershed.

### Biological and Habitat Analyses

#### Bacteriological Analyses:

The results are summarized in Figures AS1 to AS5 on schematic maps of the watershed. The results show that the measures of total coliforms were several multiples of fecal coliform counts, but, in general, rose and fell together. The WPU and IAL results on *E. coli* agree quite well, considering the inherently large error in this type of analysis and the fact that WPU’s lab methods are quite different from those used by IAL.

While the results indicate that portions of Belcher Creek and its tributaries often exceed either or both of the NJDEP’s water quality bacteria standards for fecal coliforms and *E. coli*, the counts for the Belcher Creek watershed are lower than many urban and agricultural watersheds. The results need to be evaluated in terms of changing flow conditions. Bacterial counts are affected by a number of different weather, habitat and land use conditions:

1. Bacterial counts are lowest during cold weather.
2. For the same time of year, bacterial counts will be highest for storm events that occur after long periods of dry weather.
3. The proportion of ducks relative to geese alters the bacterial counts.
4. It is often very difficult to attribute a specific land-use type (parking lots, farms, etc.) to elevated bacterial counts.

Unfortunately, because of the weather in the summer of 2009, flow conditions were not that different all summer long. The August 27th series represents the lowest flow and probably the



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longest pre-dry period. However, the other two comparison dates were periods of similar flow and similar pre-sampling rain frequency.

### **BOD:**

The values for Belcher Creek and its tributaries are all quite low, but, in general, the numbers reflect likely sources of dissolved organic matter (Figure AS6). A surprise is the relatively low values for BOD<sub>5</sub> at station BCGL5 (the only station checked on two different days) and equally low values for BCGL4 which is downstream from the Birch Hill STP. It appears that the Birch Hill plant is doing a much better job at removing oxygen-demanding organic matter than it has in the past (see Allied Biological reports). It is not clear why BCGL5 is relatively low, since the water there is very turbid with algae and obviously eutrophic. It may be that biological activity there is so high, that organisms are consuming every bit of organic matter available - at least during the daytime in summer. The outflow of West Milford Lake also exhibited a relatively high BOD<sub>5</sub> which is consistent with other water quality indicators for that small tributary.

### **Habitat:**

Some of the data and indices from the macroinvertebrate samples taken from 10 different sites on June 24, July 1, and July 14, 2009 and analyzed by Water's Edge, Baraboo, Wisconsin, are summarized in Table V-1 below. Some of these indices are also depicted in Figures AS49 to AS52. The Hilsenhoff Biotic Index is especially useful for judging the quality of the water from which the macroinvertebrates were sampled. How to interpret these numbers is described in Table V-2.

**Table V-1 – Summaries of Macroinvertebrate Sampling Data**

Sample Site BCGL-ID>	1	1a	4	5a	3	4d	5b	4a	2a	5c
Total # of organisms	80	81	83	131	251	81	40	218	156	81
Total # of (unique) genera <sup>1</sup>	16	13	12	12	11	17	10	15	19	15
% of genera that are not insects <sup>2</sup>	6.3	23.1	16.7	25.0	63.6	5.9	0.0	33.3	21.1	26.7
% Sensitive EPT individuals <sup>3</sup>	62.5	25.9	3.6	26.7	0.0	50.6	85.0	0.0	22.4	18.5
# of Scraper Genera	2	0	2	0	3	2	0	0	2	1
Hilsenhoff Biotic Index <sup>4</sup>	1.8	2.9	4.5	4.1	6.0	2.3	0.6	6.1	4.0	1.7
# of attribute 2 genera <sup>5</sup>	5	2	0	3	0	5	5	0	0	2
# of attribute 3 genera <sup>6</sup>	3	2	3	3	0	6	2	2	4	4
# EPT Taxa	9	5	3	8	2	10	7	3	6	6

<sup>1</sup> Richness measures have been calculated based on unique taxa; features were not counted as unique taxa if other individuals in the sample were identified to lower taxonomic levels within the same sample.

<sup>2</sup> % of genera that are not insects is calculated from taxa counts, not individual abundance.

<sup>3</sup> Excluding Hydropsychidae, including Dipterona.

<sup>4</sup> HBI Values (Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomologist.

<sup>5</sup> HGMI: Jessup, B. et al., 2007. Development of the New Jersey High Gradient macroinvertebrate index. Tetra Tech.

<sup>6</sup> *Ibid.*

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

**Table V-2 – Interpretation of Hilsenhoff Biotic Index**

<b>Biotic index</b>	<b>Water Quality</b>	<b>Degree of organic pollution</b>
0.00-3.50	Excellent	No apparent organic pollution
3.51-4.50	Very good	Possible slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Fair	Fairly significant organic pollution
6.51-7.50	Fairly poor	Significant organic pollution
7.51-8.50	Poor	Very significant organic pollution
8.51-10.00	Very poor	Severe organic pollution

Based on both the Hilsenhoff Index (Figure AS52) and %EPT Taxa (Figure AS50), the two sites with the highest water quality were BCGL5b Green Brook, one of the NW tributaries near Warwick Turnpike, and BCGL1, the headwater section of Belcher Creek. The lower the Hilsenhoff Index value, the higher the water quality. The Green Brook site had an index value of 0.6 (excellent water quality, no apparent organic pollution), and the headwater sampling site had an index of 1.8 (excellent water quality, no apparent organic pollution). Both sites also had the highest percentage of EPT individuals. EPT refers to the insect orders Ephemeroptera (mayfly), Plecoptera (stonefly) and Tricoptera (caddis fly). At Green Brook the %EPT was 85.0, and at the headwater site it was 62.5. Among the ten sites sampled, those two were located in the least disturbed areas of the watershed, and the macroinvertebrate analysis indicated that they had the highest water quality. A third site, BCGL5c on Cooley Brook, also had a low Hilsenhoff Index of 1.7 (excellent water quality; no apparent organic pollution), but the %EPT was only 18.5. Although the %EPT was low, the Cooley Brook site sample had 27% hellgrammites, which seemed unusual for the watershed.

Based on the Hilsenhoff Index, the two sites with the lowest water quality were the outflow stream at Pinecliff Lake and the outflow stream from West Milford Lake. The outflow from Pinecliff Lake had a Hilsenhoff Index of 6.0 (fair water quality; fairly significant organic pollution), and the outflow stream from West Milford Lake had a Hilsenhoff Index of 6.1 (fair water quality; fairly significant organic pollution). Neither sampling site had sensitive EPT organisms (0 %EPT), indicating that the water quality was too low to support mayflies, stoneflies and selected caddis flies at those locations.

Site BCGL4d on Morestown Brook, upstream of the Birch Hill STP had a Hilsenhoff Index of 2.3 (excellent water quality; no apparent organic pollution) and 50.6 %EPT. That section of Morestown Brook was relatively undisturbed, although it traversed the properties of a small residential area located near the Christian Life Center. The sampling site BCGL1a downstream of a sewage treatment plant [Crescent Park] had an unexpectedly low Hilsenhoff Index of 2.9 (excellent water quality; no apparent organic pollution).

## G. DISCUSSION & RECOMMENDATIONS

### Hydrology

As noted above the most remarkable observation to come from these data is the larger than expected flow from Green and Cooley Brooks (NW tributaries). These two streams must be

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

receiving considerable groundwater flow. This is an important observation since this flow enters Belcher Creek just before it enters Greenwood Lake. The water in these NW tributaries is very high quality - at least down to the point where it passes behind the A&P. That flow is significantly diluting Belcher Creek in a positive way.

### Water Quality

#### Discrete Field Measurements:

Field measurement of water variables (temperature, conductivity, dissolved oxygen and pH) were all within more-or-less normal range. The most significant of these measures is the dissolved oxygen concentration, which was, for the most part, always close to oxygen saturation. However, these discrete measurements were all made during daylight hours. As noted below, continuous monitoring of dissolved oxygen at all hours does reveal some oxygen stress on the stream's water. In conjunction with the observation that stream flow in Belcher Creek this year was uniformly moderate to strong because of the frequent rainfall events, it may be concluded that, at least this summer, Belcher Creek exhibited sufficient "assimilative capacity" to prevent in-stream respiration from severely lowering the dissolved oxygen levels.

Measures of turbidity were also well within "normal" values for an urban stream; namely, they were low enough to rule out significant suspended solid input due to sources of sediment influx. Increases in turbidity appear to be related to the growth of floral and faunal plankton in the stream not sediment eroded by runoff.

#### Continuous Field Measurements:

1. Temperature varies diurnally - peaking about 2PM with a minimum about 2AM.
2. Specific conductance drops rapidly during precipitation events (Figure A54). Positive spikes suggest some sort of artificial addition to the stream - pool water, sewage outflow, car washing, etc.
3. Dissolved oxygen (DO), when the instrument worked properly, peaks around the same time as temperature during the day but has a minimum before midnight. When the probe worked, it shows stream water mostly slightly supersaturated. Only one record, from Stowaway Road, BCGL2, shows very wide swings in DO. The other sites indicate DO was relatively constant.
4. pH does not vary much at three of the sites. It has a diurnal variation which mimics DO - as the plants photosynthesize, they draw down the CO<sub>2</sub> raising the pH. Precipitation (acid) events drop the pH. Note that the Stowaway Road site (BCGL2) has the greatest range in pH and also DO which points to significant biological activity which is evident visually as well.

#### Fluorometry:

Although there is some indication that the measurements have picked up some sources of sewage inflow and these roughly correspond to known Belcher Creek sewage treatment plants (STPs), there are some glaring exceptions - most notably the NW tributary site had a very high fluorescence, but, in general, has the best water quality otherwise and no real possible sources upstream in Hewitt Forest. It is likely that some other organic chemical, probably natural, is in this water. We did note during a reconnaissance hike up in Hewitt State Forest that both Green and Cooley Brooks have large areas of wetlands in their upper basins. The water in the stream is brown with humic acids up there, but clear by the time it reaches Warwick Turnpike.

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

One thing to note from these results is that the pattern of response versus time is nearly flat for all analyses. This indicated that there were no nearby sources - the streams were well mixed with respect to fluorescing compounds at all points sampled.

### **Chemical Analyses:**

There are many conclusions that could be “mined” from the chemical data:

1. Chemical analyses clearly reflect the influence of both “clean” sources of water at stream headwaters and the influence of “dirty” inflows from STPs and polluted water bodies like West Milford Lake.
2. Dissolved nitrogen concentrations in Belcher Creek water are surprisingly low. The decline of nitrate N is so dramatic that it clearly points to N-consumption in excess of input along most of the length of Belcher Creek and its tributaries. This result is consistent with previous observations that Belcher Creek/Greenwood Lake approaches, and occasionally achieves, nitrogen-limitation. The obvious conclusion is that phosphorus is in such abundant supply that nitrogen has a hard time “keeping up.”
3. There appears to be a distinctive chemical “signal” associated with STPs – this shows up more clearly in the Tri-linear diagram.
4. Nitrate, as already mentioned in discussion of overall chemistry, is very dynamic within this aquatic system which tends toward nitrogen-limitation.
5. Phosphorus levels are clearly related to STPs. However, as can be seen by comparing the results for Coyote Cove versus Olde Milford STP downstream (Coyote Cove is about 0.5 kilometer downstream from Olde Milford STP), Belcher Creek and its tributaries are doing a good job of assimilating the nutrients input, at least during this wet past several months.
6. Pinecliff Lake (and system of wetlands above it) is a sink for P as well as N. Whether this is released at other times of the year remains a question.
7. Nutrient levels are higher during low-flow periods than higher flows, as one would expect. The low-flow sampling of August 27<sup>th</sup> is affected by the STP input more than the higher flows during June and July.

As noted by Wetzel (1983) aquatic systems like lakes with dissolved P concentrations less than 10 ppb (ug/L) would be expected to be oligotrophic (low productivity, clear-water lakes); while lakes with P concentrations greater than 30 ppb (ug/L) would be eutrophic (high productivity, “green-water” lakes). As applied to Greenwood Lake itself (sample site BCGL6 in this study) Wetzel’s analysis would imply that Greenwood Lake is eutrophic, which is very apparently true. However, as noted by Allan (1995) and others, the same P concentration limits do not necessarily apply to running waters. The reasons given by Allan and others to explain why this is so are complex, but, essentially the principal factor involved in the distinction between the trophic states of running vs. still waters lies in the more dynamic nature of nutrient exchange in rivers and streams vs. lakes and ponds. Hence, levels of P and/or N in lakes that would clearly be indicative of eutrophication may have far less effect on the trophic status of a stream. That distinction appears to clearly hold for Belcher Creek. Both N and P are clearly very dynamic within the stream’s waters. And, only where the stream assumes “lake-like” behavior – at the upper reaches of Pinecliff Lake and in the wide inlet just south of the Creek’s entrance into Greenwood Lake, does the stream channel exhibit the high levels of productivity characteristic of a eutrophic water body. Hence, in general, one would expect that the characteristics of eutrophication (algal blooms, wide swings in dissolved oxygen, fish kills, etc.) would be related to the overall flow rate of the stream – more eutrophic in drought years and more oligotrophic in wet years. As noted above, the summer of 2009 was a notably “wet” year in the sense that

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

frequent rains kept all sections of the stream and its tributaries flowing during the entire monitoring season.

### **Bacteriological Analyses:**

Some general observations on the results of bacteriological sampling follow:

1. There is an absence of any strong trend in bacterial counts along the length of the main channel of Belcher Creek. Rather the counts appear to reflect local influences of the numerous tributaries to the main stream. If anything, bacterial abundances often decrease downstream. This suggests that processes that promote bacterial death and/or settling are effectively removing introduced fecal bacteria from the stream's water.
2. High counts for West Milford Lake and Morestown Brook are offset by the relatively small contribution of these flows to the overall discharge of Belcher Creek.
3. In general, tributaries with high water quality, as indicated by chemical analysis, had low bacteria counts – for example, Green and Cooley Brooks and the small stream that enters Pinecliff Lake along its western edge identified here as Bearfort Road.
4. Similar to what happens with nutrients, Pinecliff Lake appears to be a “sink” for bacteria at least under some flow conditions. This “sink” appears to happen very rapidly under some flow conditions in the area of Stowaway Road perhaps even above it in the wetlands along Union Valley Road.
5. While there is some indication that the STPs are one source of fecal bacteria, other sources appear to be equally or more important. For example, there is no STP associated with West Milford Lake. Likewise, the high bacterial counts in the lower portion of Belcher Creek below Pinecliff Lake seem to be related to wildlife rather than human pollution.

### **Summary Recommendations**

Belcher Creek is a stream that is under considerable stress from multiple sources – input of nutrients and organic matter from several point sources; influx of dissolved constituents from both point and non-point sources; and a modest bacteriological burden that may originate from minor agricultural activity. Despite these environmental insults, however, the stream, for the most part is “coping” – it has maintained fair to good habitat quality along most of its length, moderately high dissolved oxygen levels, and, in general, apparent freedom from toxic pollutants. At the same time, however, the stream is undoubtedly delivering to Greenwood Lake a level of nutrients that the Lake itself cannot fully assimilate. There seems to be little question that in the absence of the nutrient burden delivered to Greenwood Lake by Belcher Creek, the Lake would have improved water quality. Similarly, it seems obvious that the Creek-Lake system is at a precarious stage where any further stress in the form of nutrient inputs would lead to further degradation of water quality in both the stream and the Lake. Hence, Dr. Pardi and Dr. Sebetich would recommend the following:

- Do no further harm – limit further residential and commercial development and, where such development does occur, apply strict controls to the release of nutrients to surface water.
- Protect and possibly expand wetlands.
- Reduce the release of nutrients from sewage treatment plants and septic systems.

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### H. PROJECT REVIEW AND RECOMMENDATIONS

**Anne L. Kruger, Ph.D., Senior Scientist, Passaic River Coalition**

After reviewing the data gathered during this project Dr. Kruger recommends that the following findings be emphasized in implementing actions to restore the natural resources of the Greenwood Lake Watershed in New Jersey:

- ◆ Nitrogen (N) levels, as well as phosphorus (P) levels, in waters entering Greenwood Lake from Belcher Creek are “limiting”, and, therefore, must be reduced to reduce eutrophication in the Belcher Creek watershed as well as Greenwood Lake (Figure AS38 on page V-61).
- ◆ The Hilsenhoff Biotic Index from macroinvertebrate sampling data and other data clearly show that the waters coming out of Pinecliff Lake (BCGL3) and West Milford Lake (BCGL4a) have “fairly significant organic pollution” (Table V-2).
- ◆ The “larger than expected flow” from Green and Cooley Brooks (NW tributaries) demonstrates the value of undeveloped, naturally vegetated lands storing groundwater and transmitting clean water supplies to Belcher Creek and Greenwood Lake.

Dr. Kruger recommends that the following potential actions be given high priority.

#### **Reduce Nitrogen (N) Levels as well as Phosphorus (P) Levels:**

- ◆ Reduce both N and P loadings from stormwater runoff by installing stormwater retrofits or BMPs (Best Management Practices) at high priority sites (Figure III-4), and routinely clean out the sediment and plant material that collects in these devices and other stormwater basins. Removing these materials from stormwater is critical for reducing the inputs of N and P into Greenwood Lake.
- ◆ Reduce discharges of both N and P, as well as raw sewage, from sewage treatment plants.
- ◆ Reduce discharges of N from septic systems, as discussed in Section IV (pages IV-9 *et seq.*).
- ◆ Improve the capacity of wetlands in the watershed to denitrify, that is to convert nitrate in the water to nitrogen gas in the air. This is done by protecting or restoring the natural functioning of a wetland. Wetlands in the watershed are shown in Figure II.C-2. Emergent wetlands that especially need to be conserved are shown in Figure II.C-7.
- ◆ Clean up the debris that collects beside streams and lakes.

#### **Reduce Pollution in and from Pinecliff Lake and West Milford Lake:**

- ◆ Study and address the nutrient pollution coming into and out of these lakes, even though this pollution is ignored in the “Total Maximum Daily Load (TMDL) for Phosphorus to Address Greenwood Lake” because most of this pollution stays in the lakes.
- ◆ Monitor on a routine basis in the future the quality of the water leaving Pinecliff Lake (BCGL3) and West Milford Lake (BCGL4a), as well as that entering Greenwood Lake (BCGL6) in order to measure progress in efforts to restore the waters of the Belcher Creek watershed and Greenwood Lake to less eutrophic conditions.

#### **Increase Ground Water Flows as Base Flows into Streams and Greenwood Lake:**

- ◆ Preserve additional lands with high water resource values (Figure III-5) as dedicated “Open Space”. As a priority, acquire and dedicate vacant land in the watersheds of Green and Cooley Brooks as well as the headwaters of Belcher Creek.
- ◆ Increase ground water recharge.
- ◆ Encourage water conservation.
- ◆ Adopt a stream corridor protection ordinance.

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- ◆ Assure that the Highlands Regional Master Plan can be legally implemented in the near future.
- ◆ Establish educational materials to show the public how they may participate in creating a cleaner environment.

### I. SCHEMATIC MAPS AND OTHER FIGURES

The following set of figures is used to summarize the results of the field and laboratory analyses of samples from Belcher Creek and its tributaries and Greenwood Lake. The schematic maps of the Belcher Creek watershed (AS) are sparse line drawings in standard map orientation used to summarize series of measurements at specific points and/or times within the watershed. Different text colors have been used to differentiate different types of measures or different times of measurement. The profile figures (AP) show selected measurement values of some water quality variables plotted as a function of distance upstream on the main channel of Belcher Creek from its confluence with Greenwood Lake.

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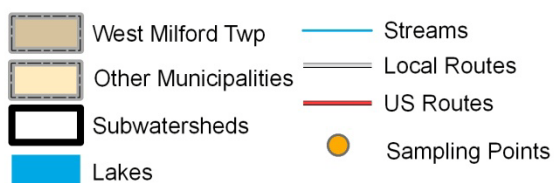
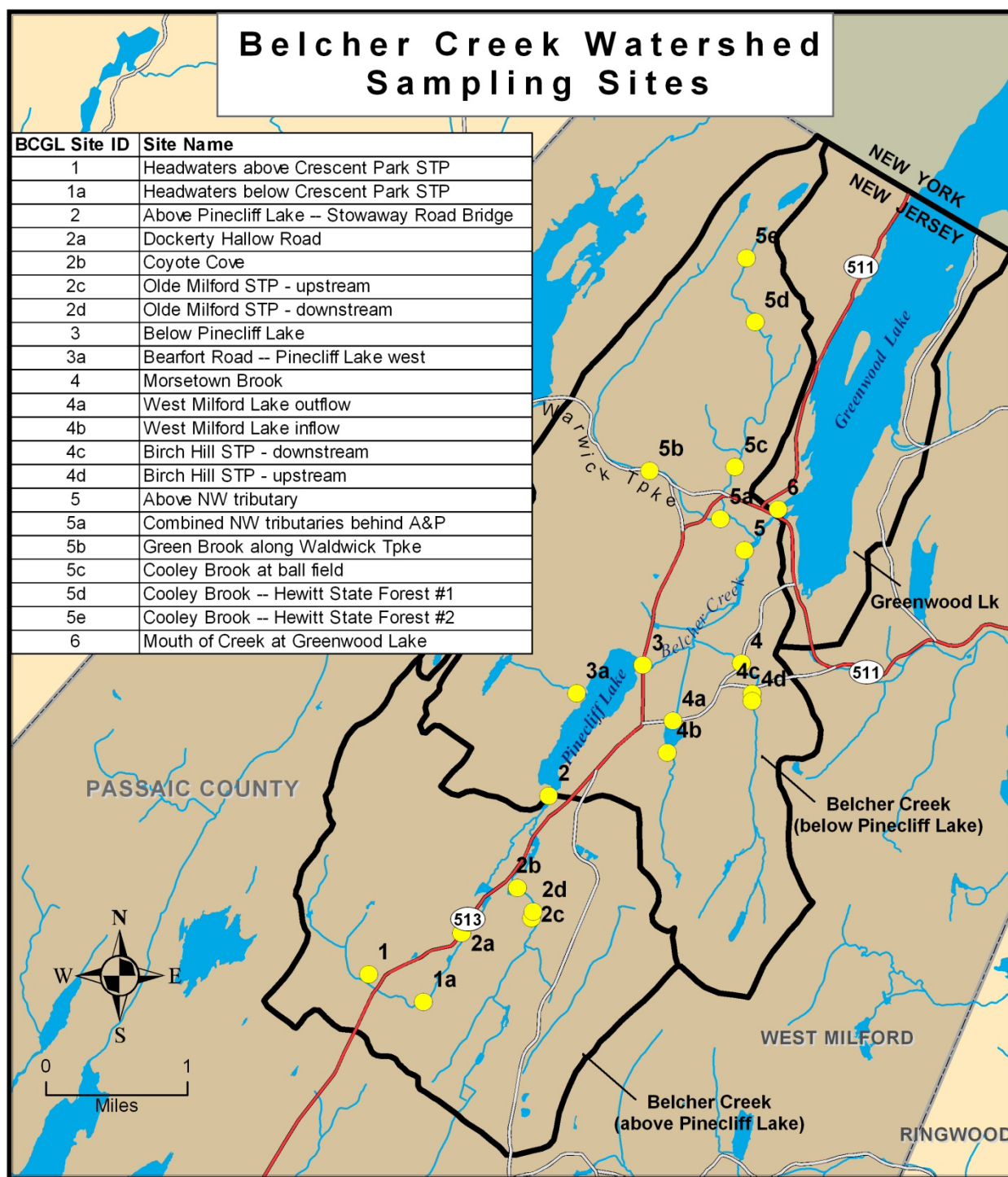


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**Figure A-1 – Field Sampling Sites in Waters of the Belcher Creek Watershed**



Sources: NJDEP GIS digital data. This map has not been verified by NJDEP and is not state-authorized.

Produced in ArcView 9.2 by Allyson Salisbury, Dec. 2009

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

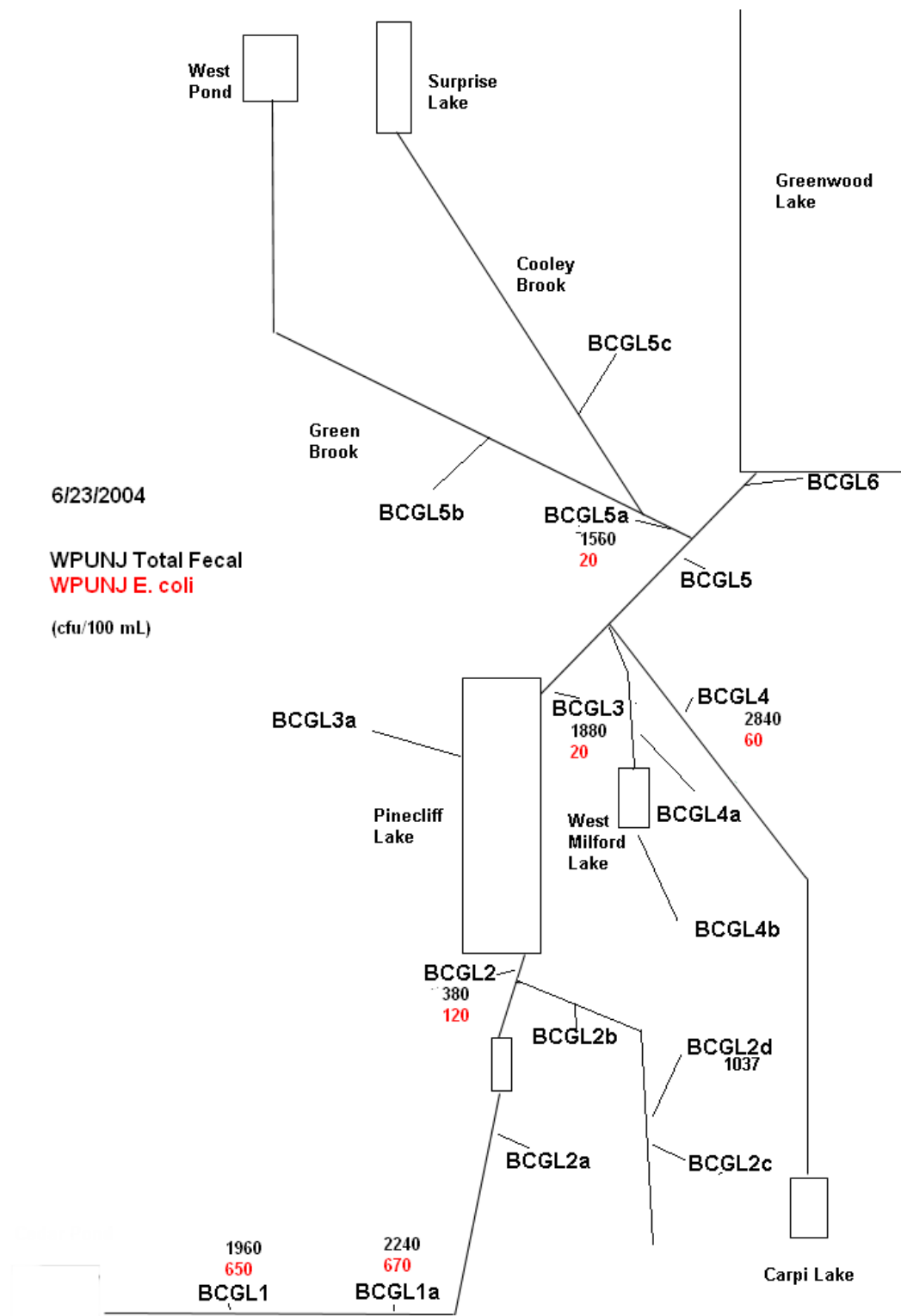


Figure AS1: Bacteriological results for Belcher Creek watershed for June 23, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

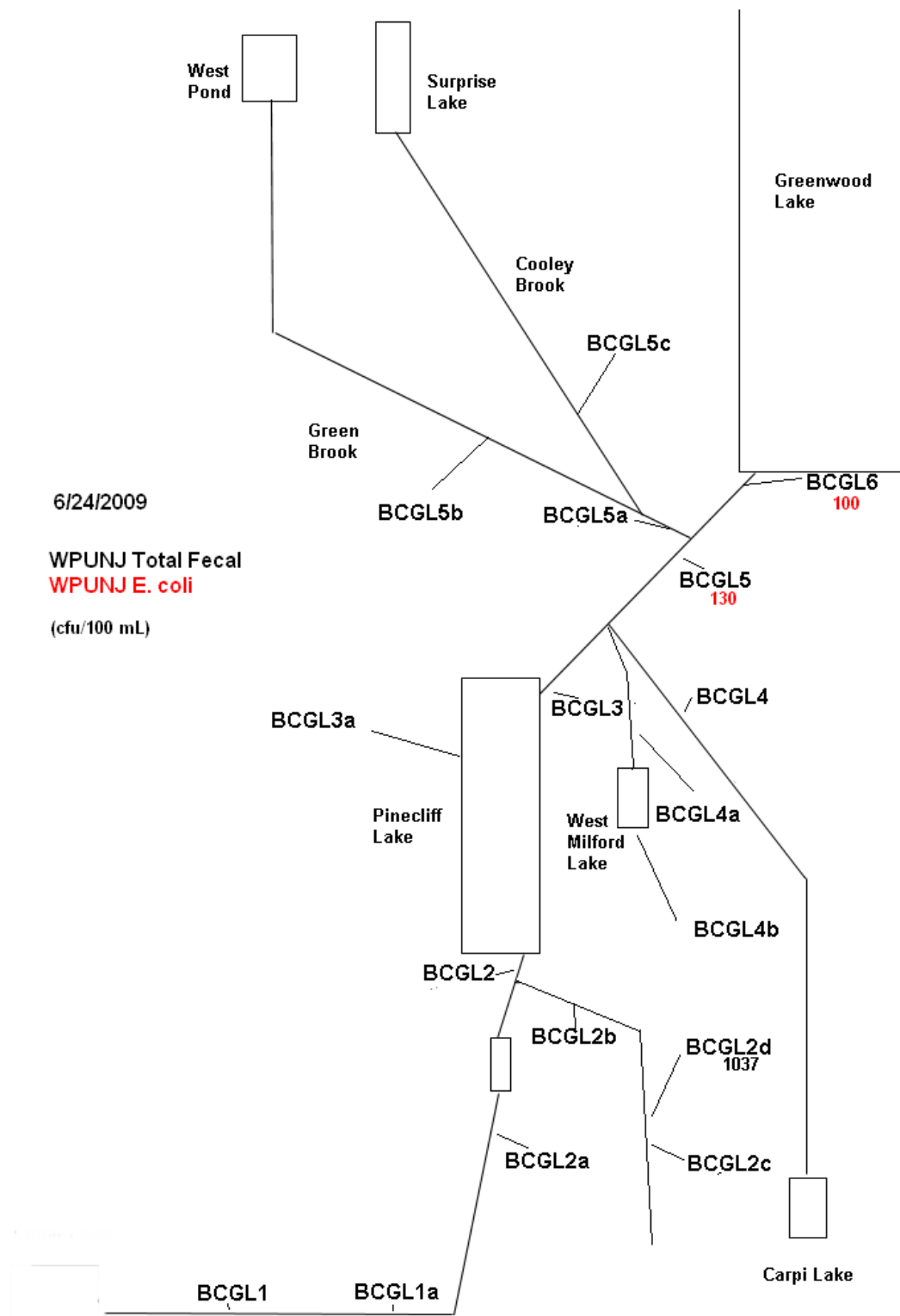


Figure AS2: Bacteriological results for Belcher Creek watershed for June 24, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

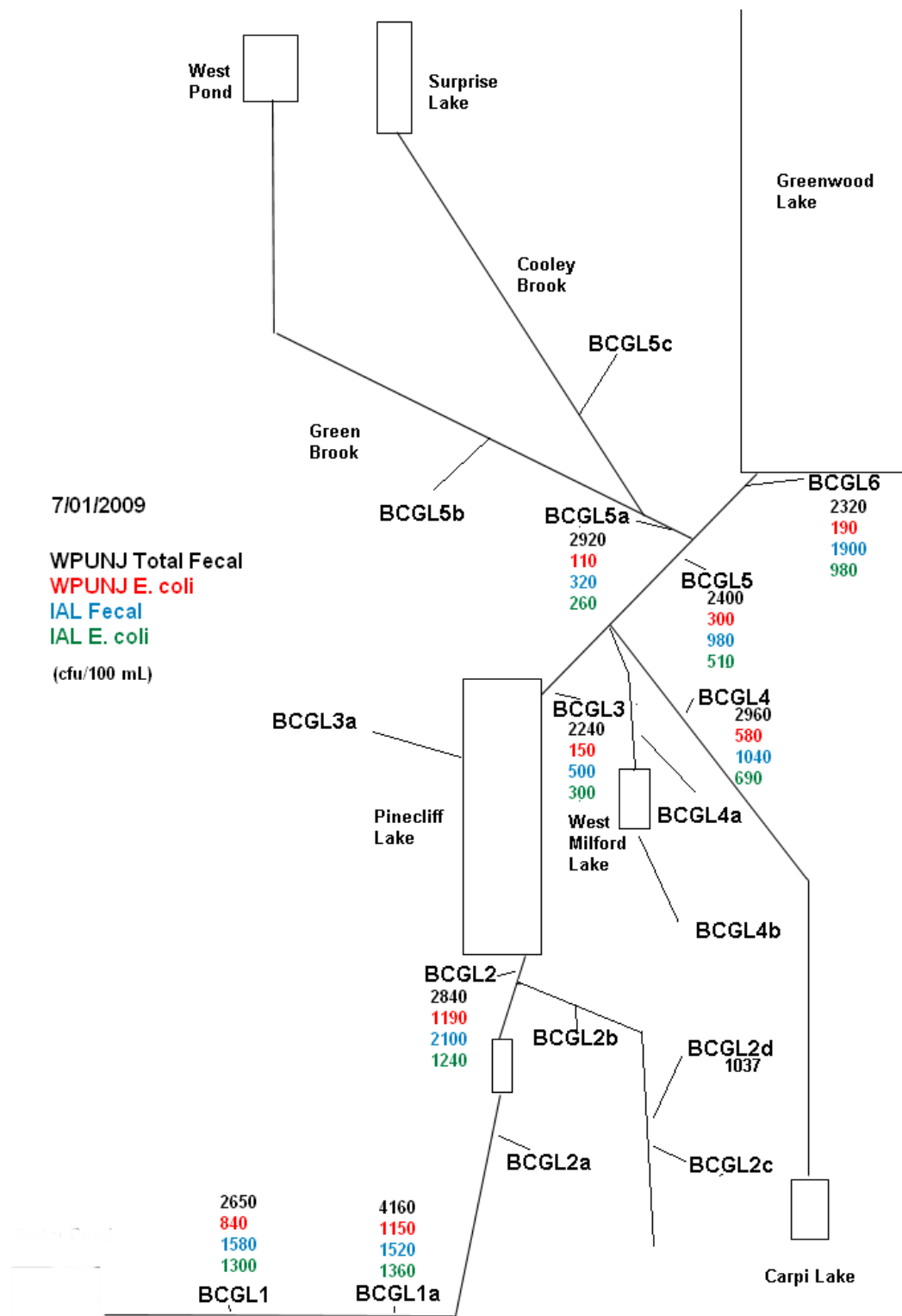


Figure AS3: Bacteriological results for Belcher Creek watershed for July 1, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

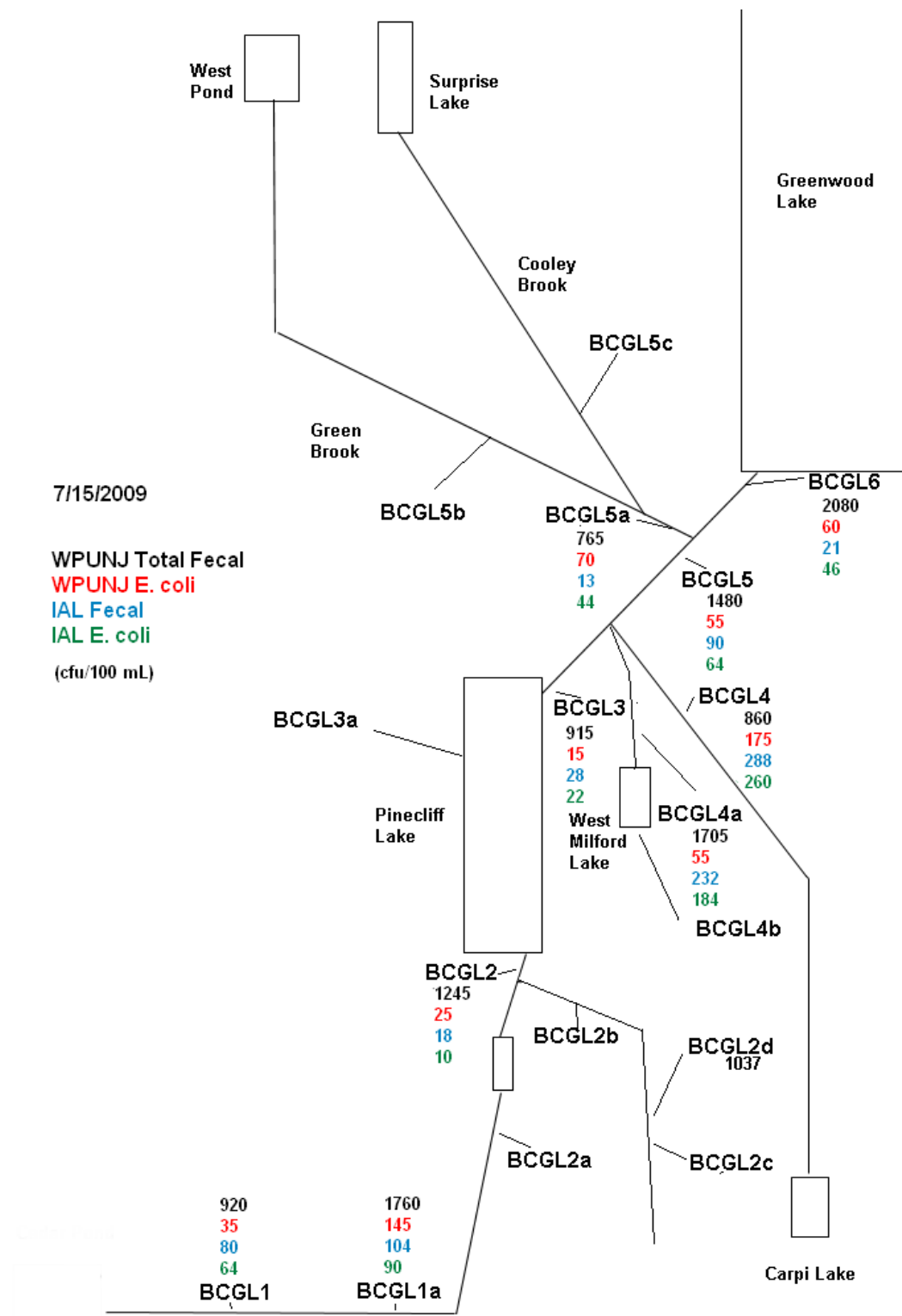


Figure AS4: Bacteriological results for Belcher Creek watershed for July 15, 2009.

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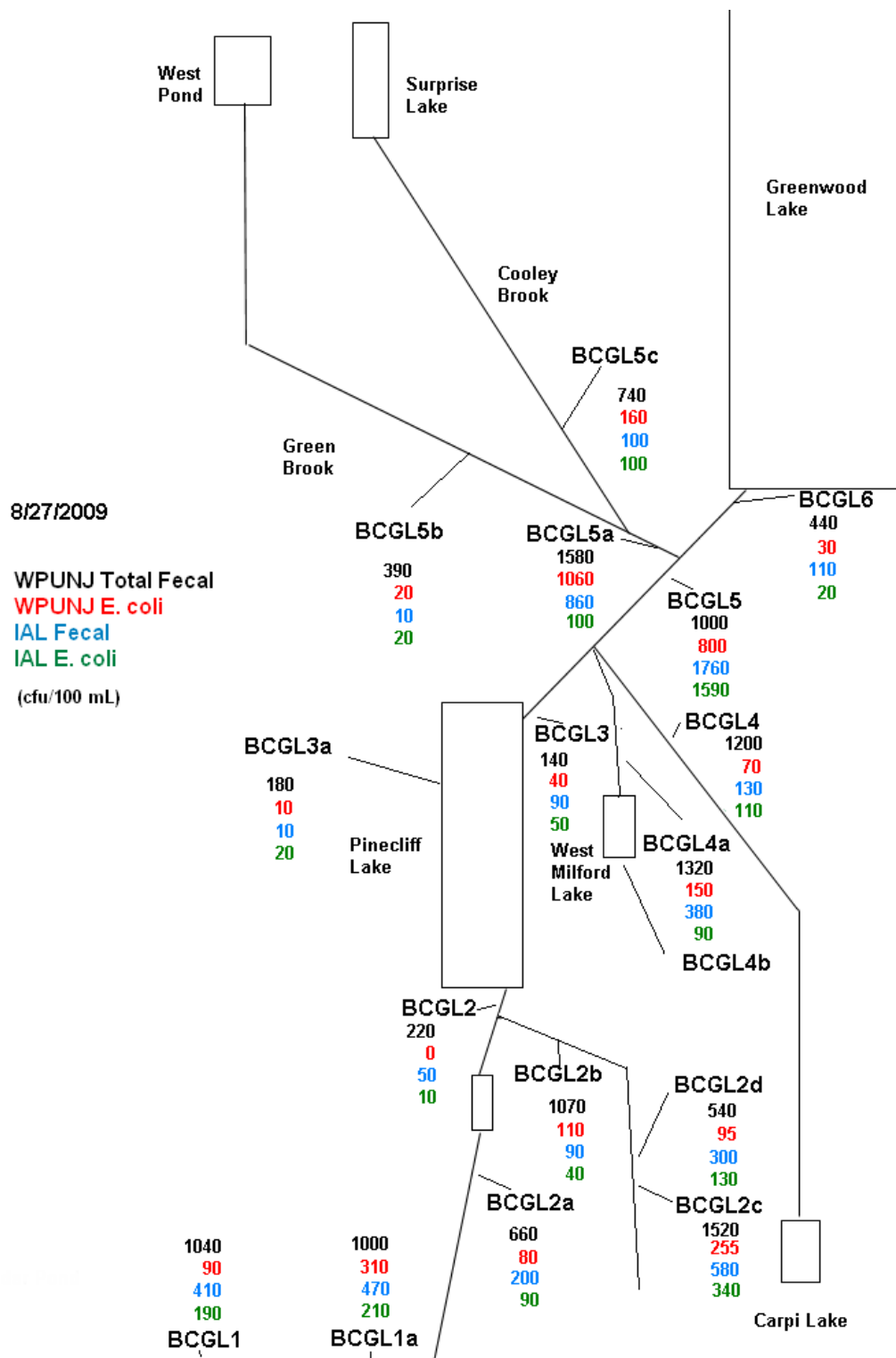


Figure AS5: Bacteriological results for Belcher Creek watershed for July 15, 2009.



# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

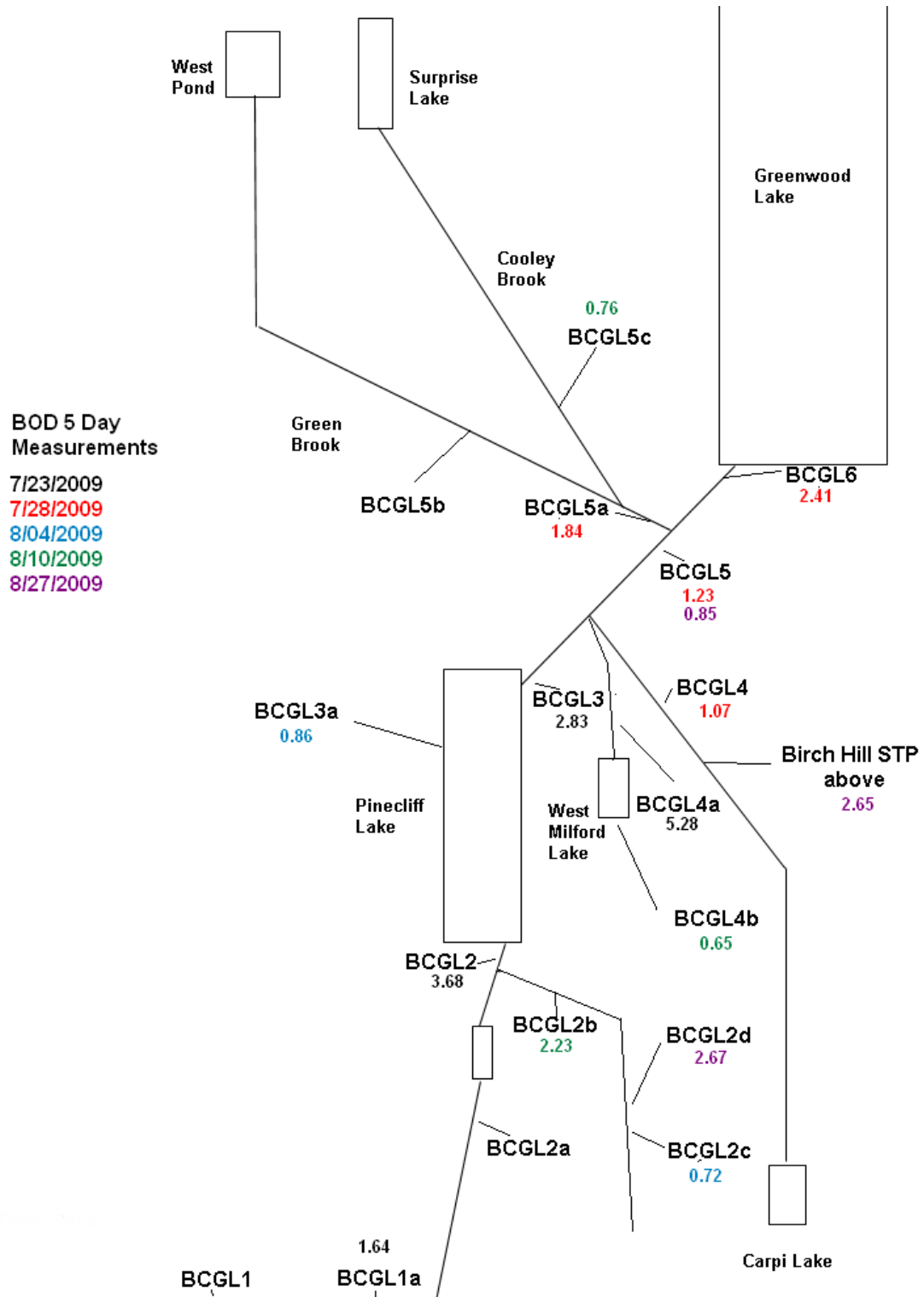


Figure AS6: Summary of BOD Measurements for 7/27, 7/28, 8/4, 8/10, & 8/27/09

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

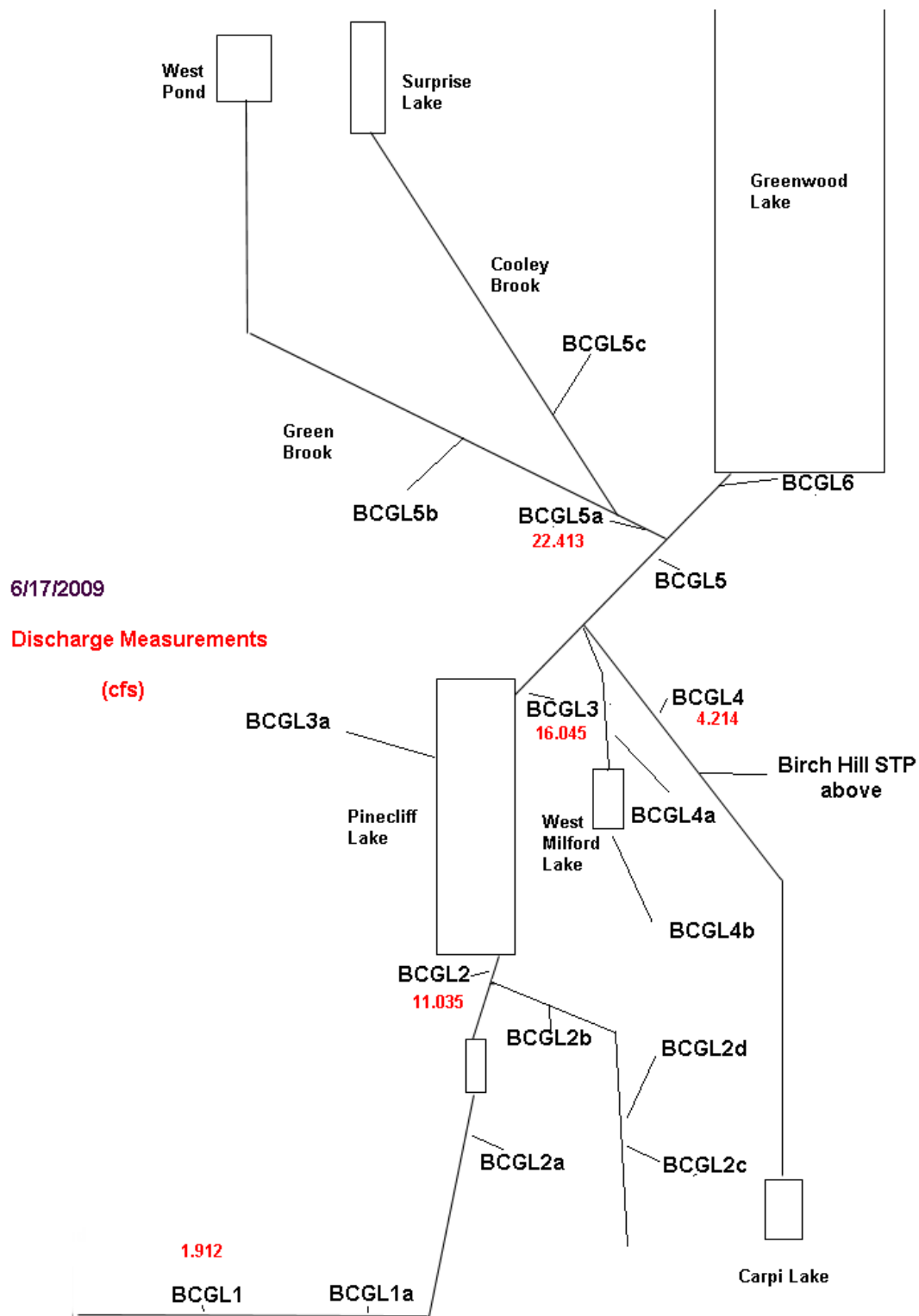


Figure AS7: Discharge measurements for June 17, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

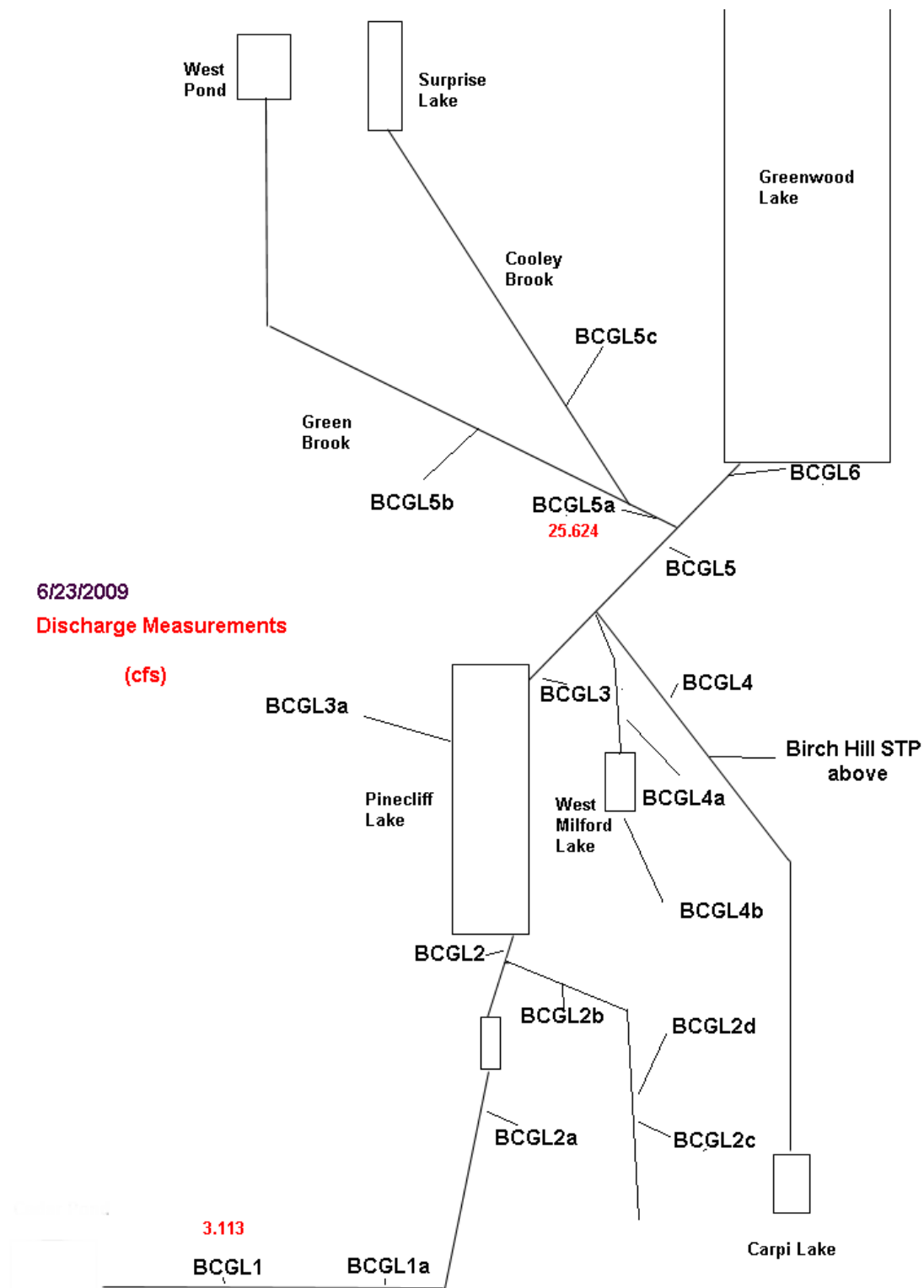


Figure AS8: Discharge measurements for June 23, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

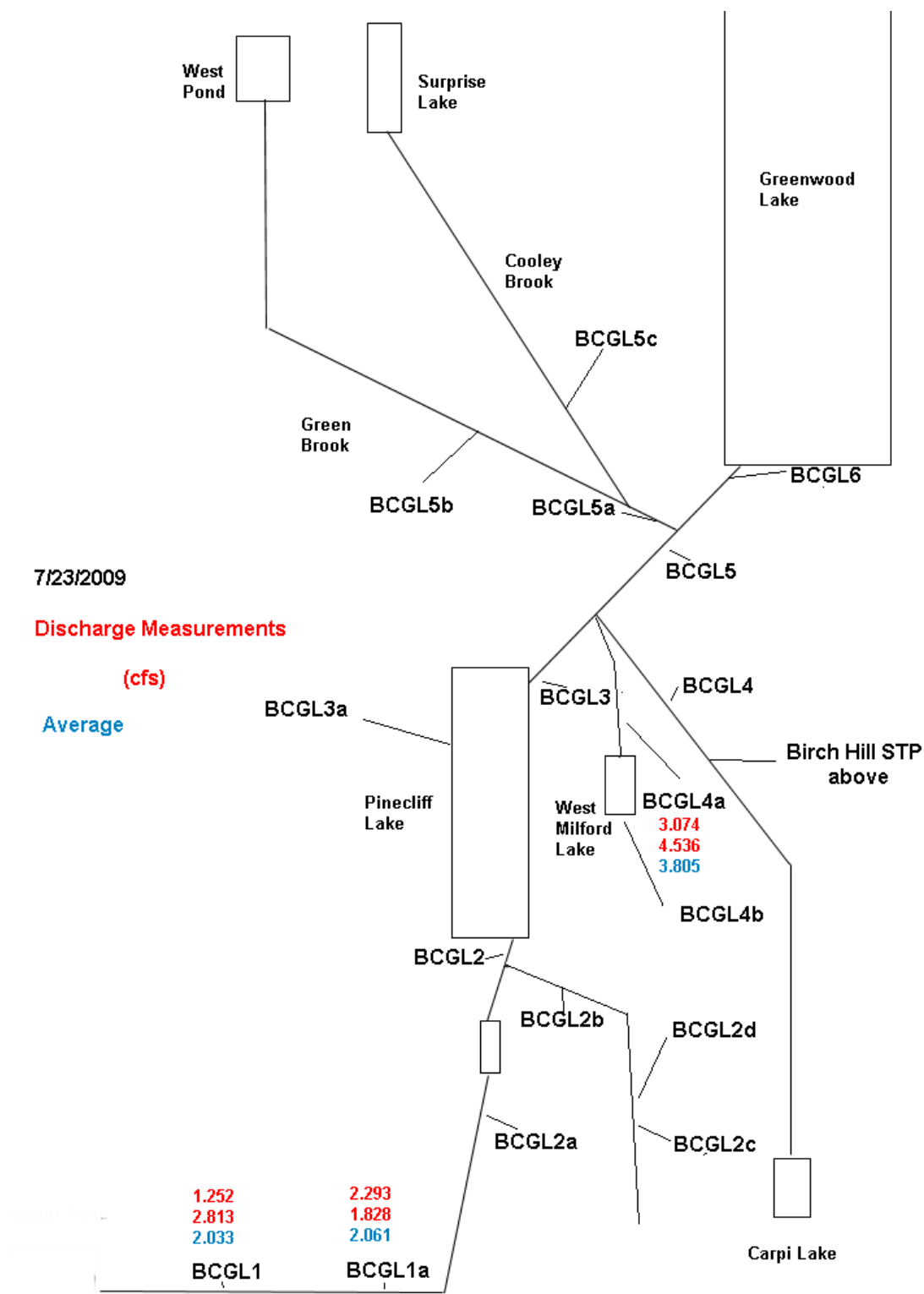


Figure AS9: Discharge measurements for July 23, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

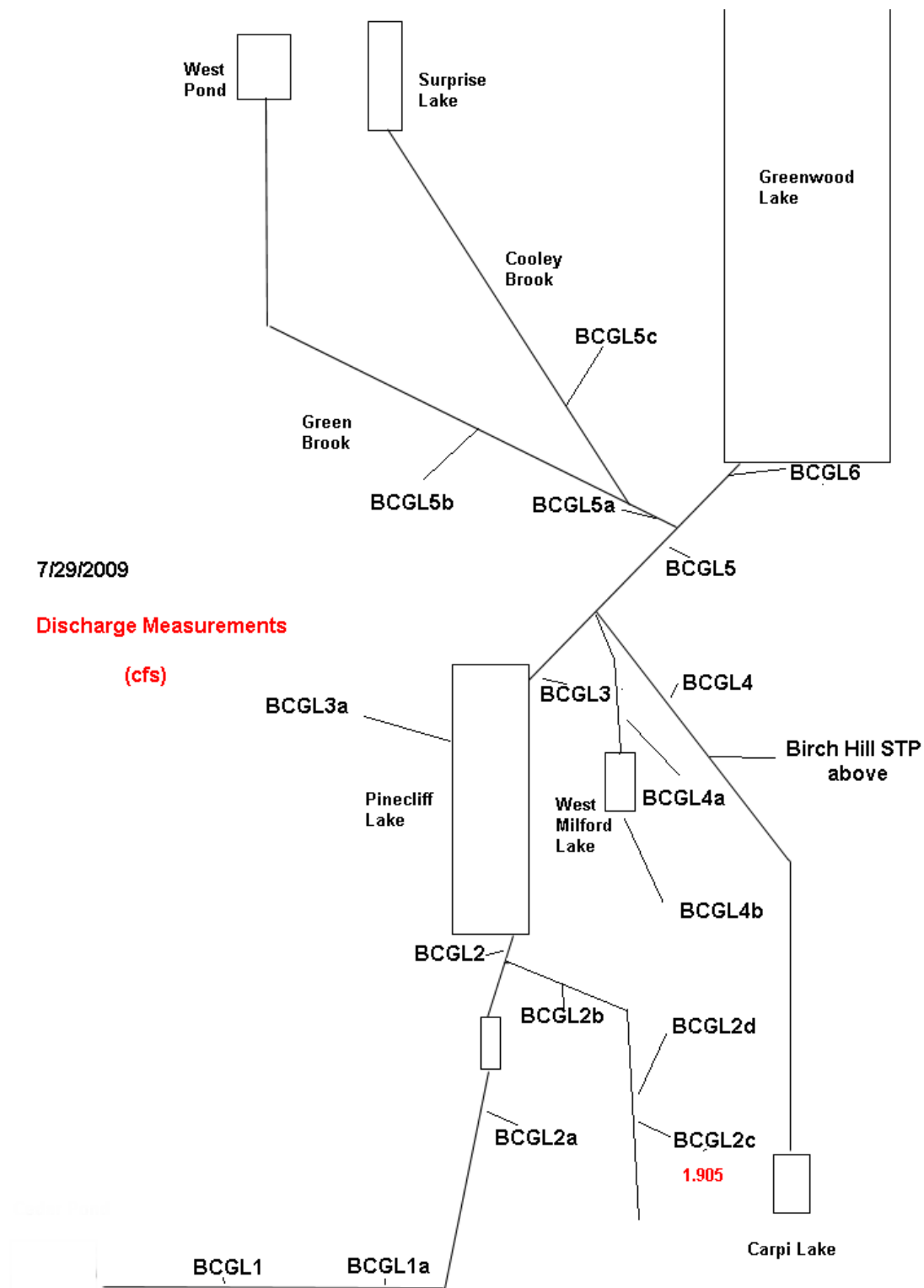


Figure AS10: Discharge measurements for July 29, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

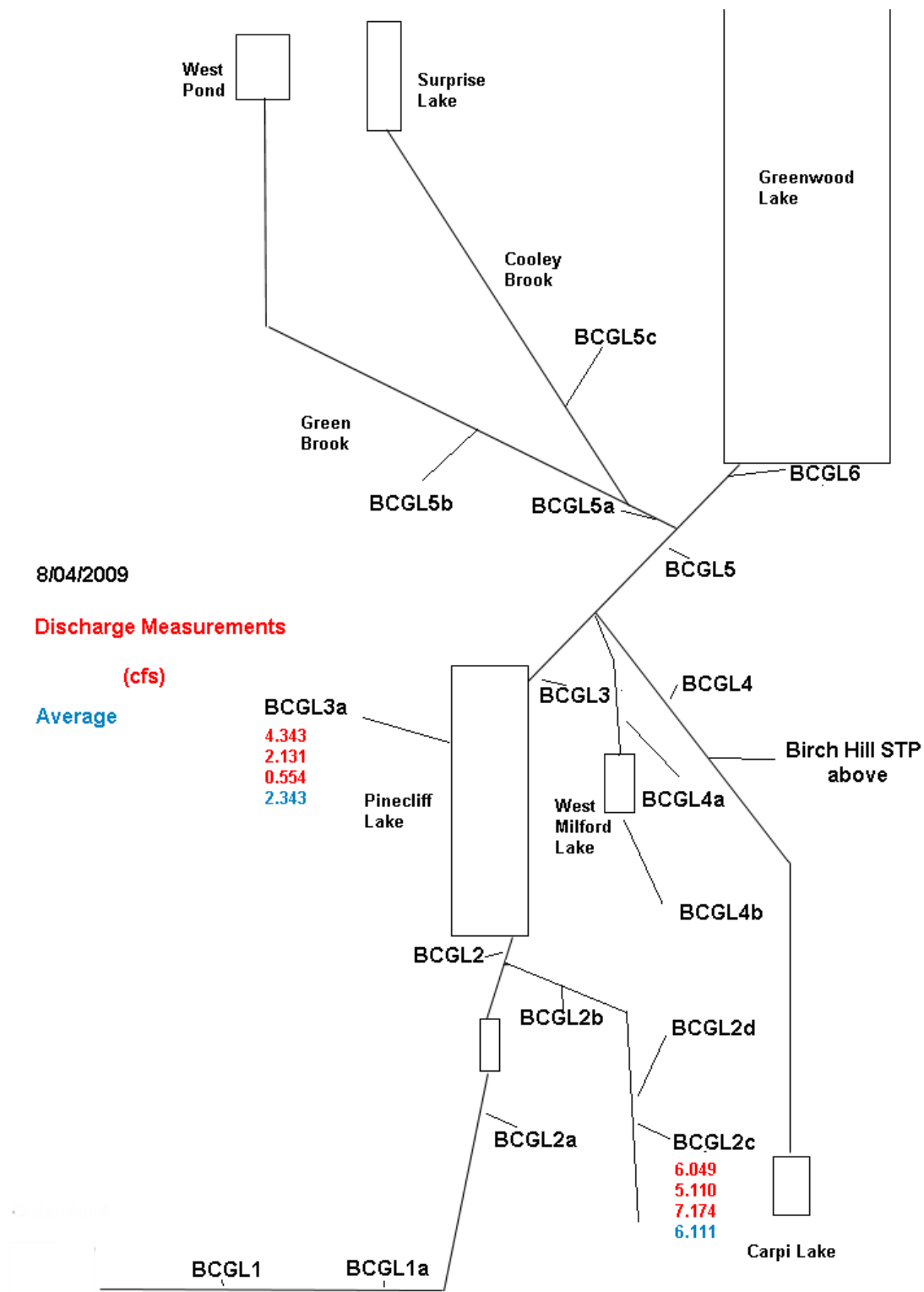


Figure AS11: Discharge measurements for August 4, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

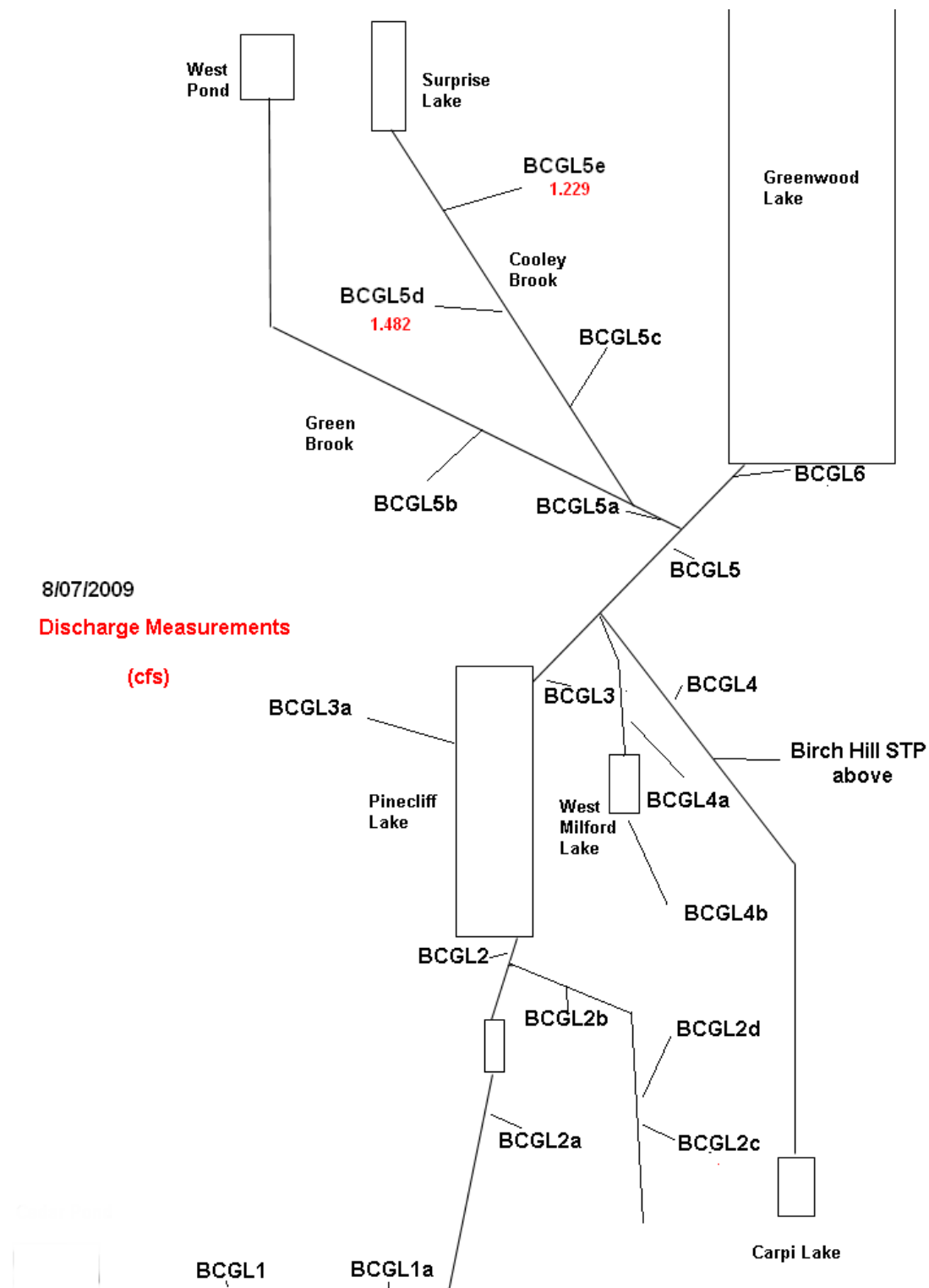


Figure AS12: Discharge measurements for August 7, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

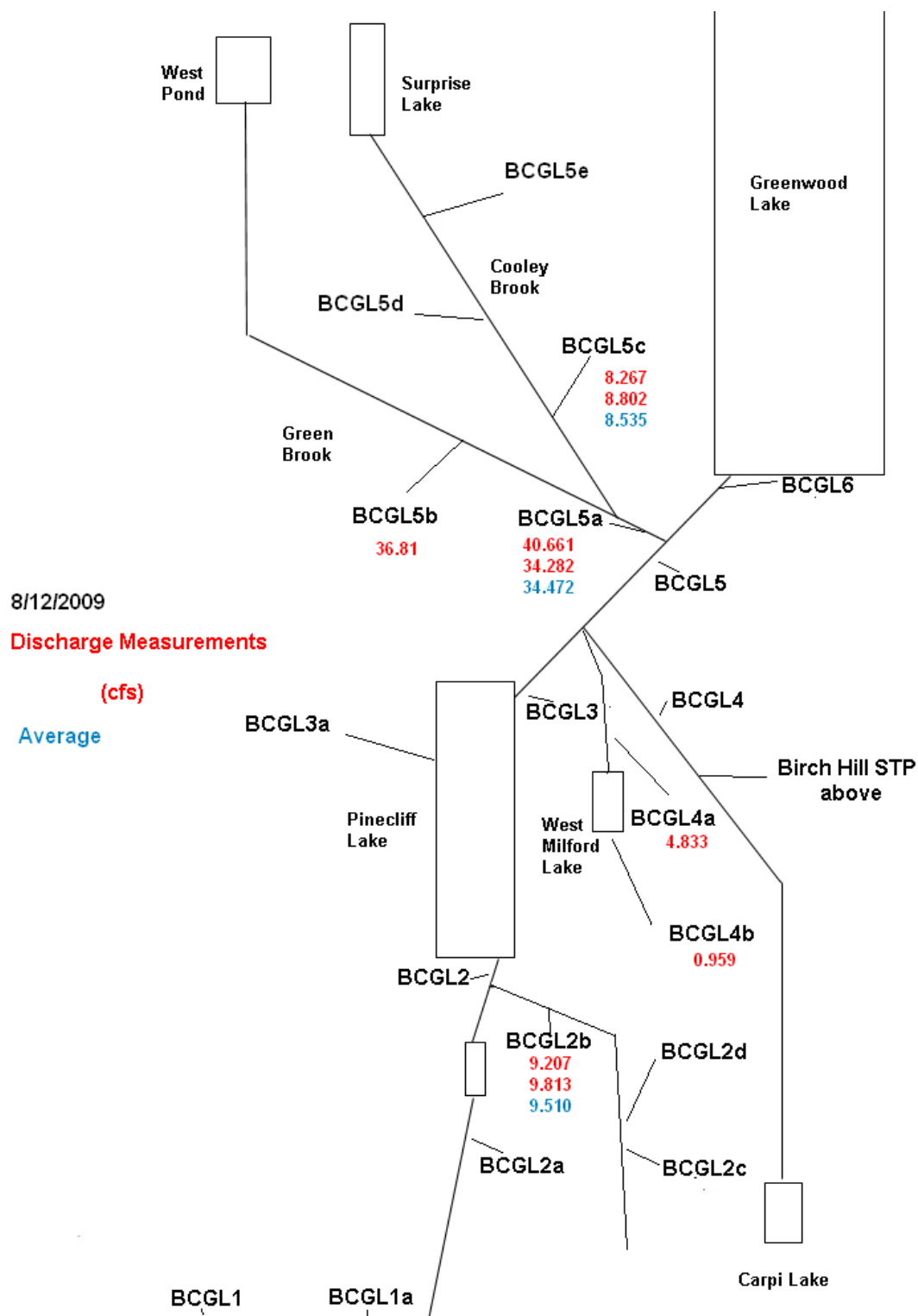


Figure AS13: Discharge measurements for August 12, 2009.



# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

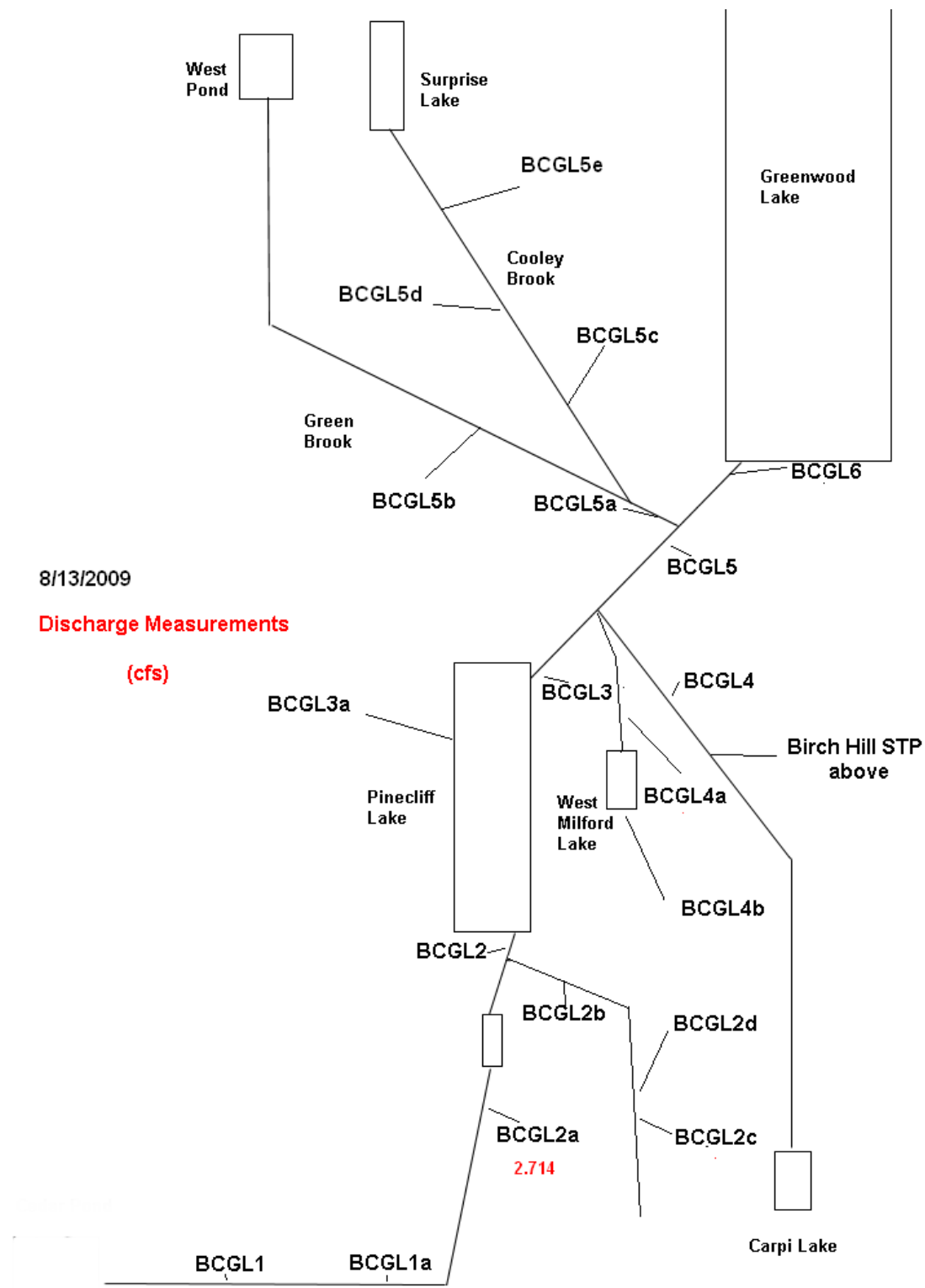


Figure AS14: Discharge measurements for August 13, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

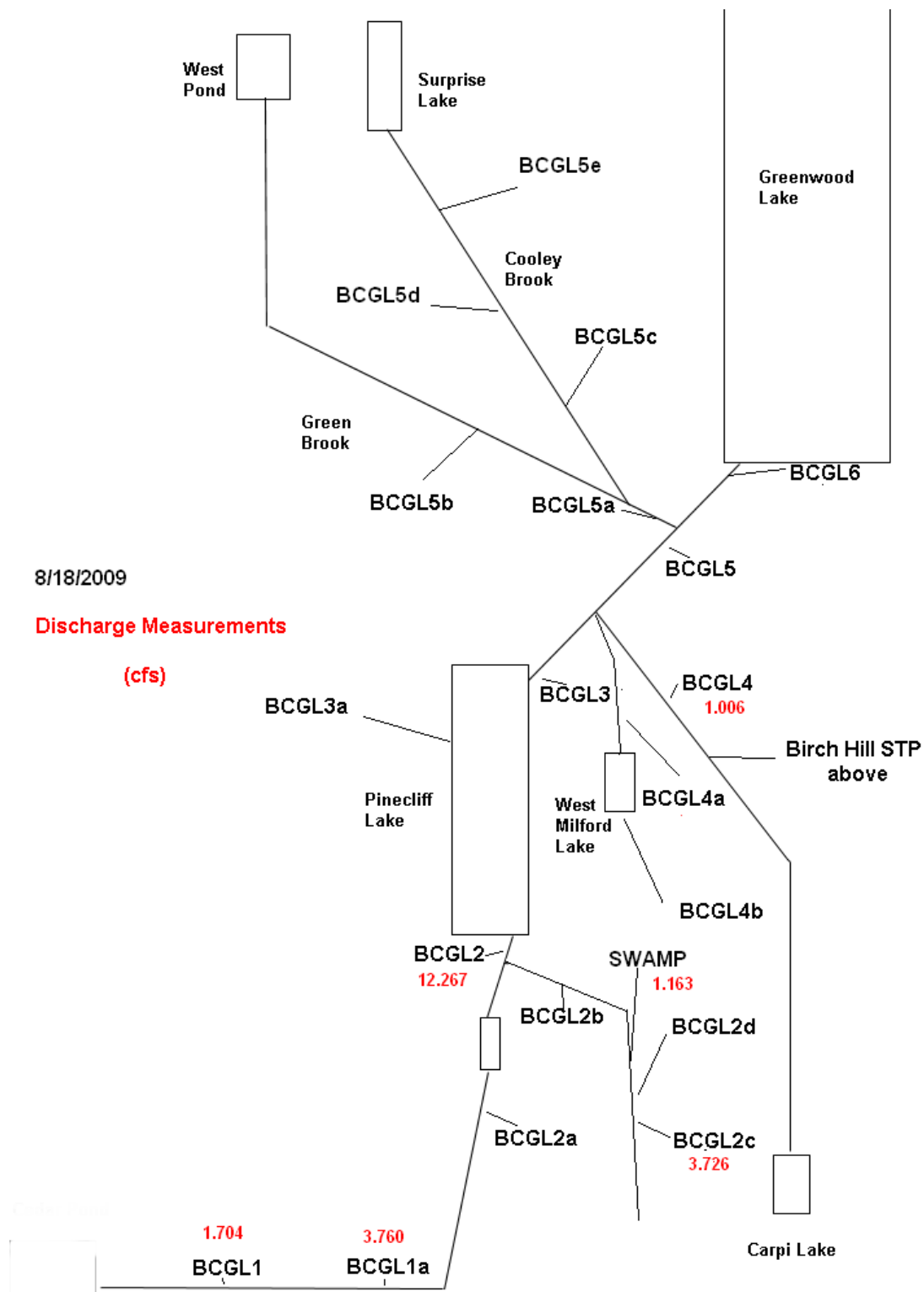


Figure AS15: Discharge measurements for August 18, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

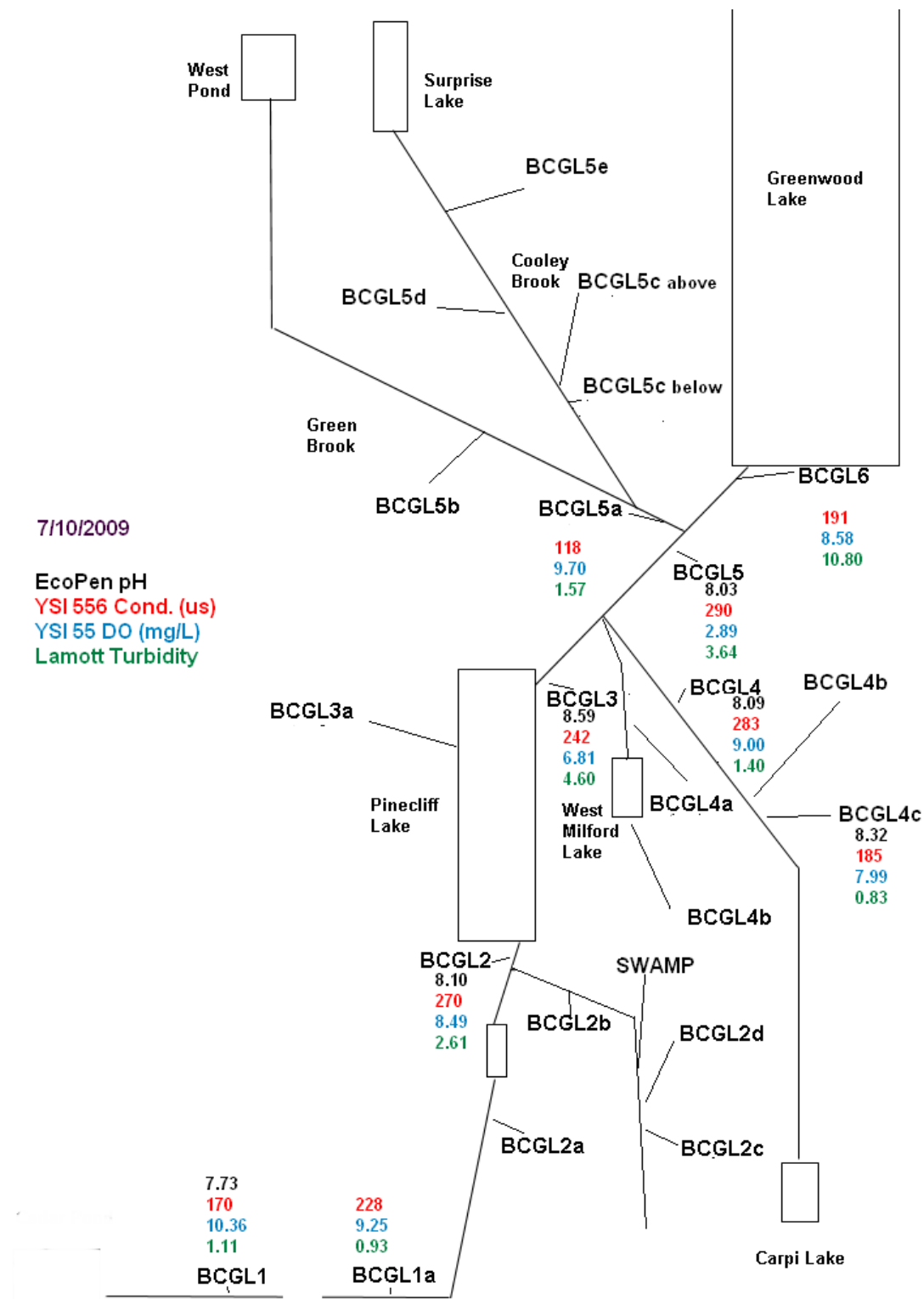


Figure AS16: Summary of Field Measurements (pH, T, DO, SC & Turb.) July 10, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

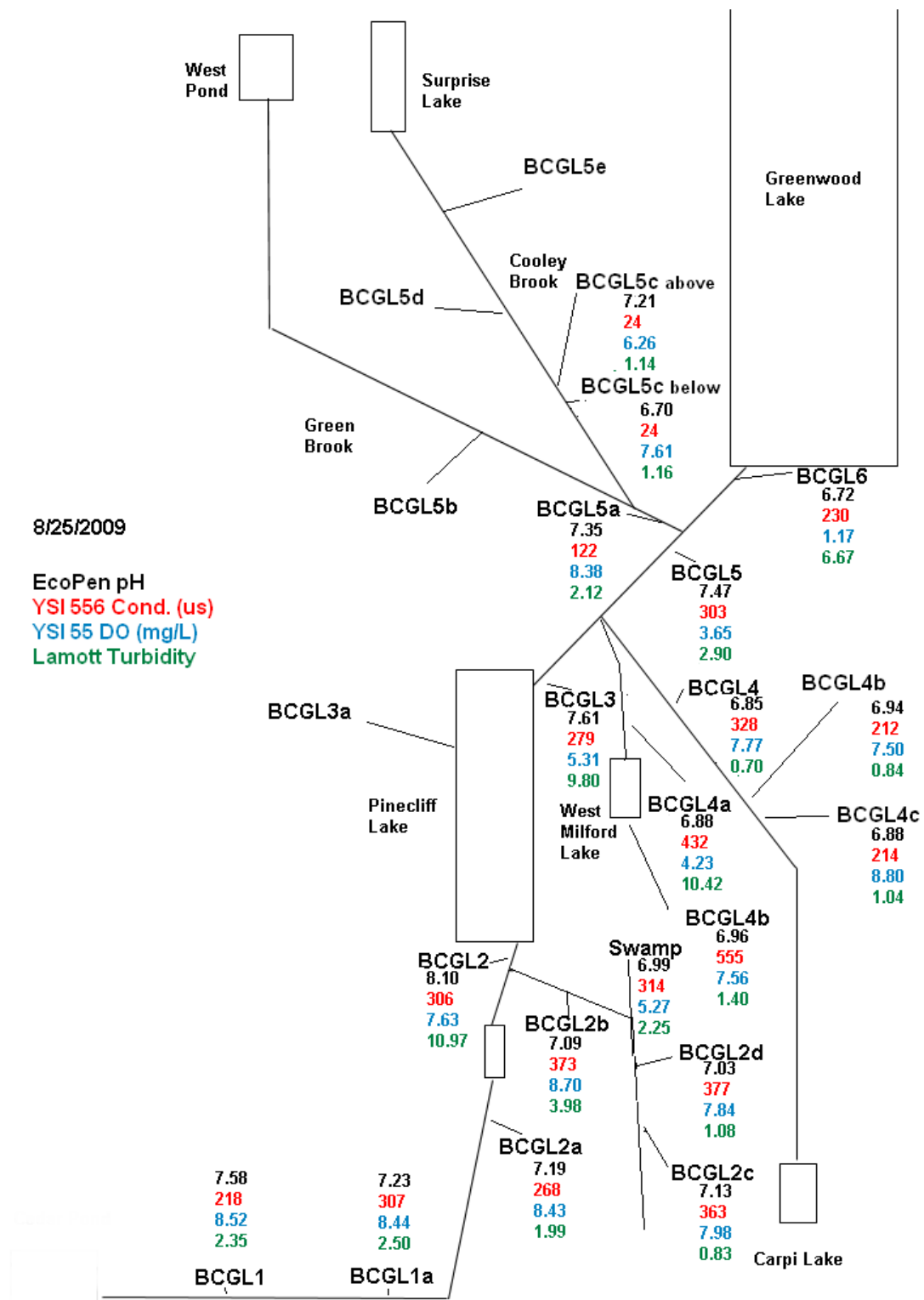


Figure AS17: Summary of Field Measurements (pH, T, DO, SC & Turb.) August 25, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

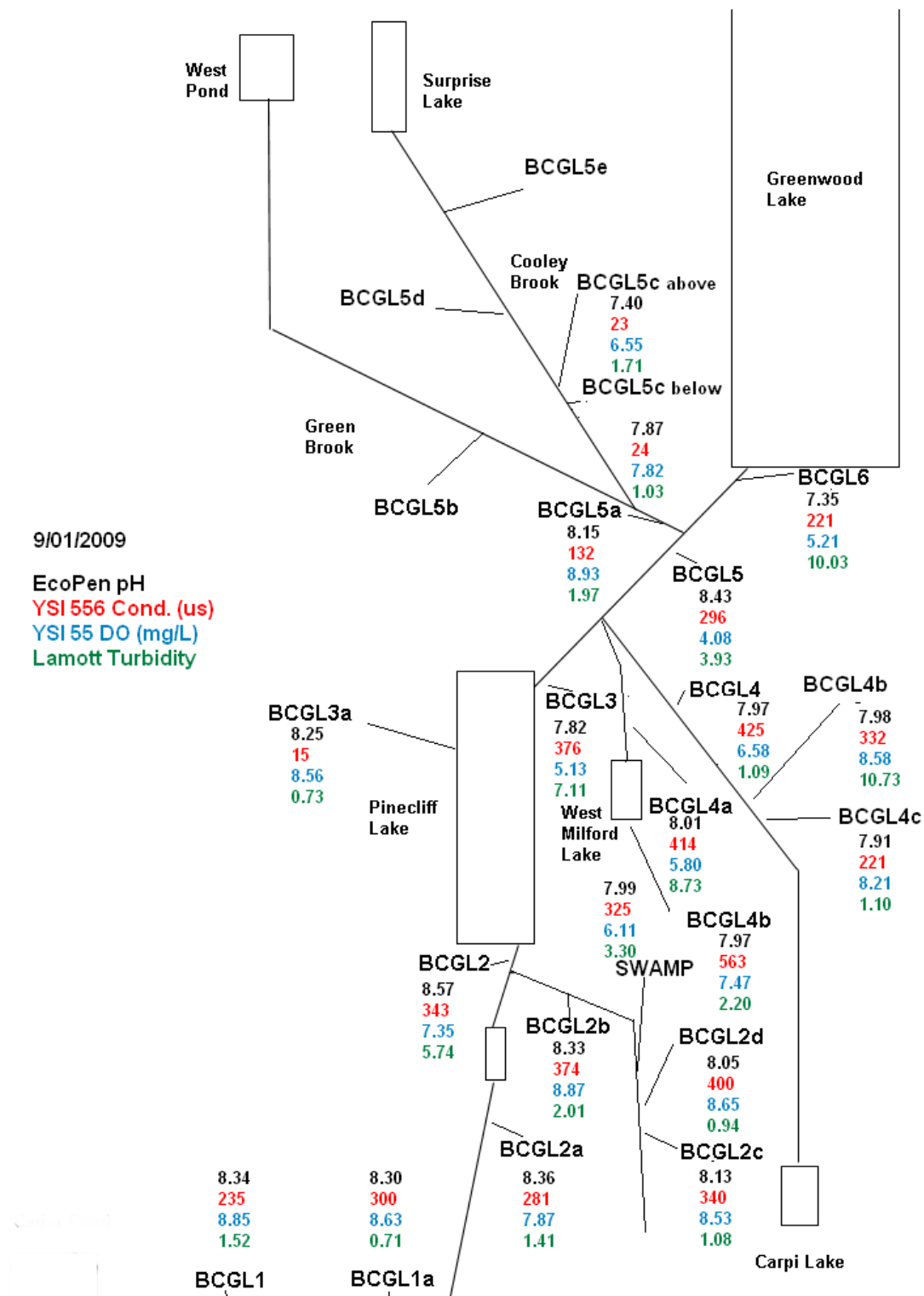


Figure AS18: Summary of Field Measurements (pH, T, DO, SC & Turb.) Sept. 1, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

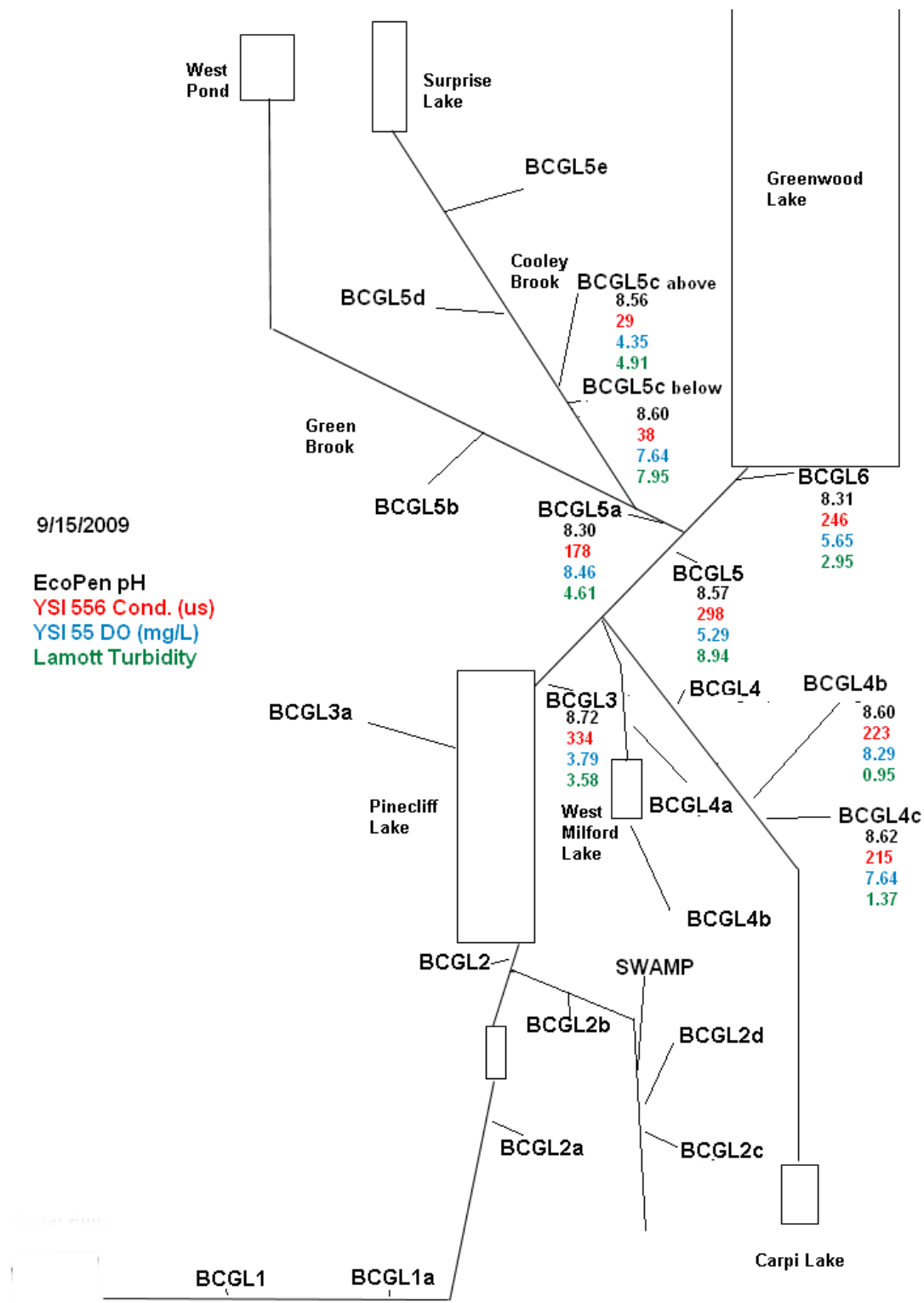


Figure AS19: Summary of Field Measurements (pH, T, DO, SC & Turb.) Sept. 15, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

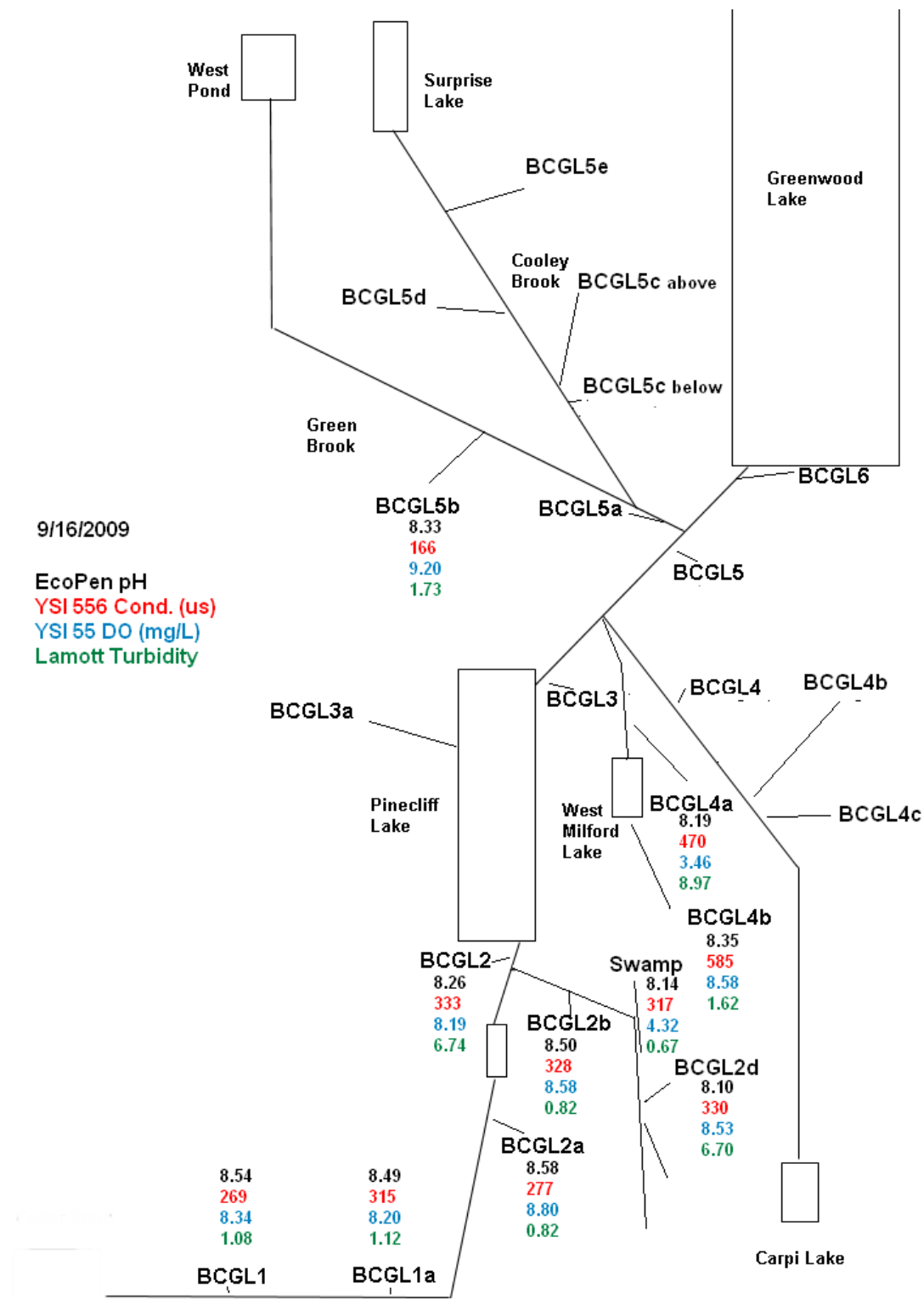


Figure AS20: Summary of Field Measurements (pH, T, DO, SC & Turb.) Sept. 16, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

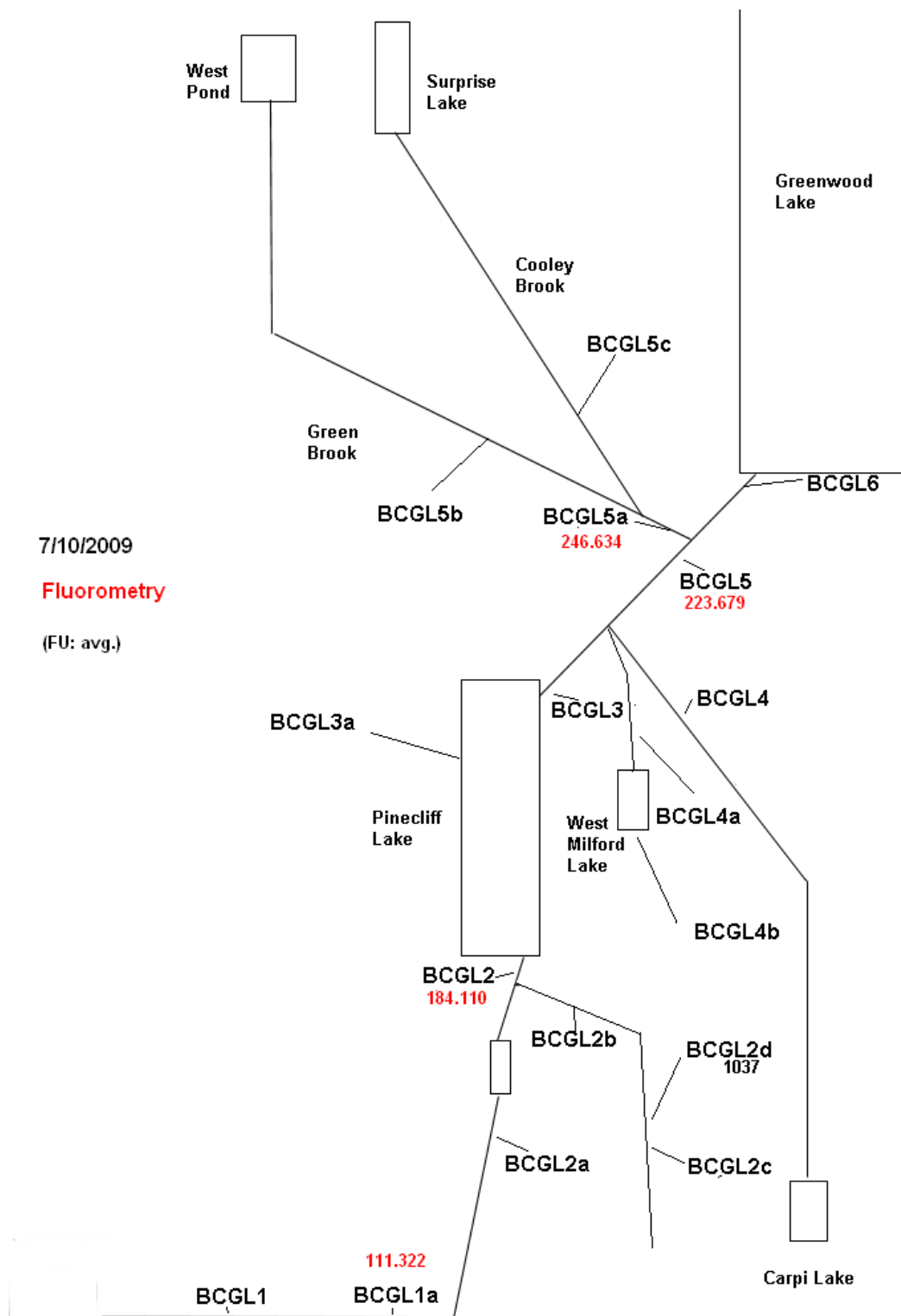


Figure AS21: Summary of Fluorometric Measurements July 10, 2009.



# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

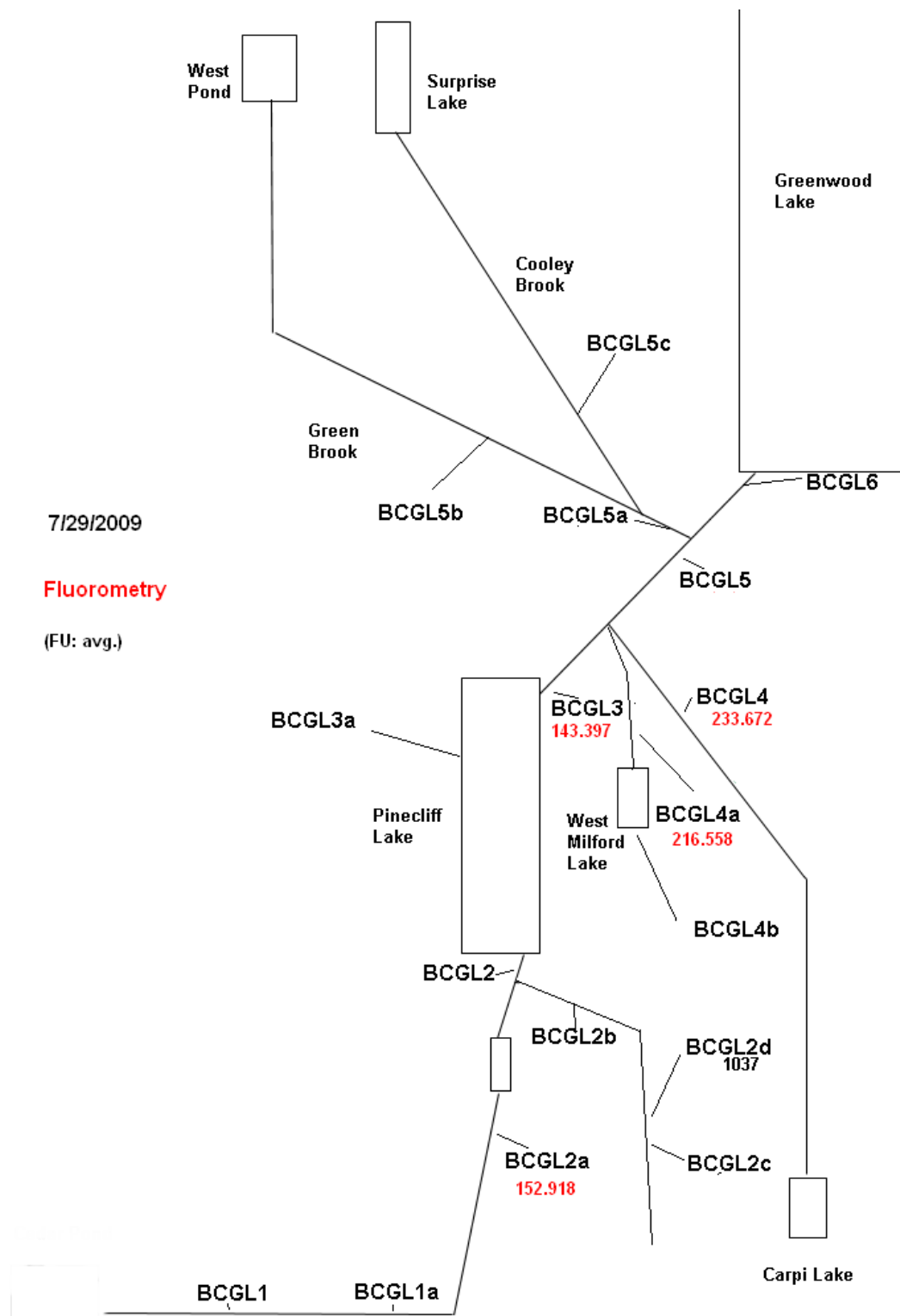


Figure AS22: Summary of Fluorometric Measurements July 29, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

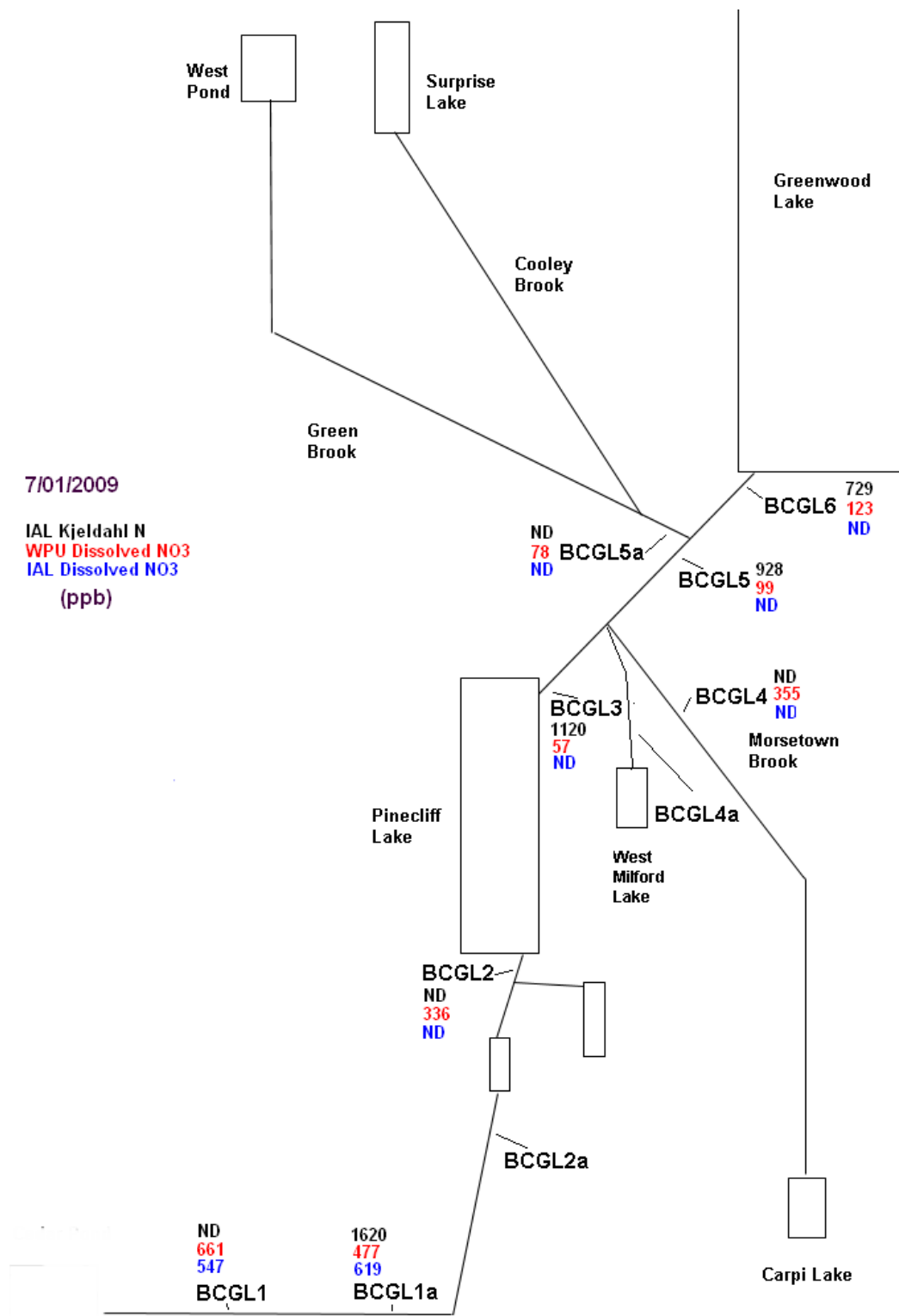


Figure AS23: Summary of Nitrogen Measurements July 1, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

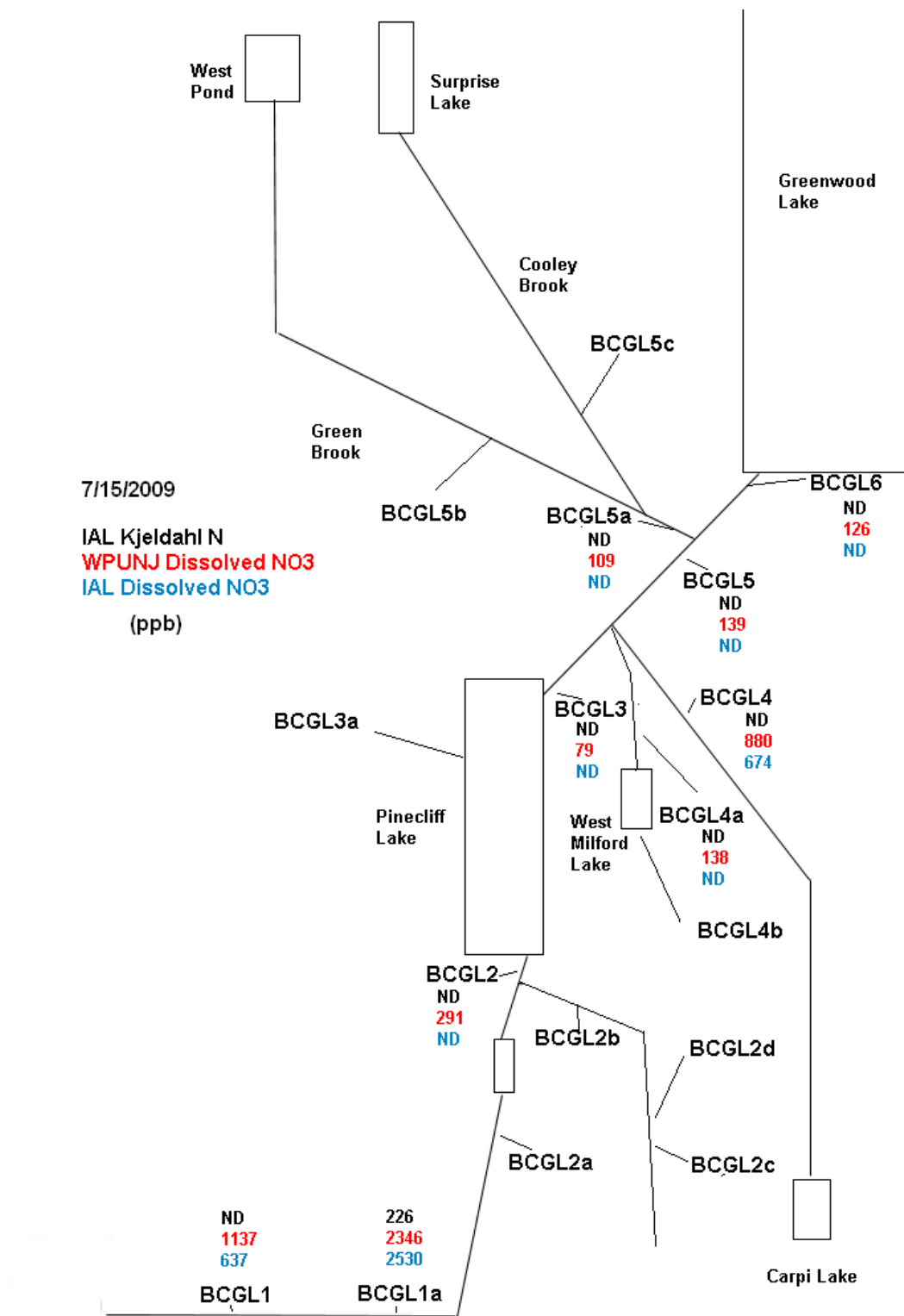


Figure AS24: Summary of Nitrogen Measurements July 15, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

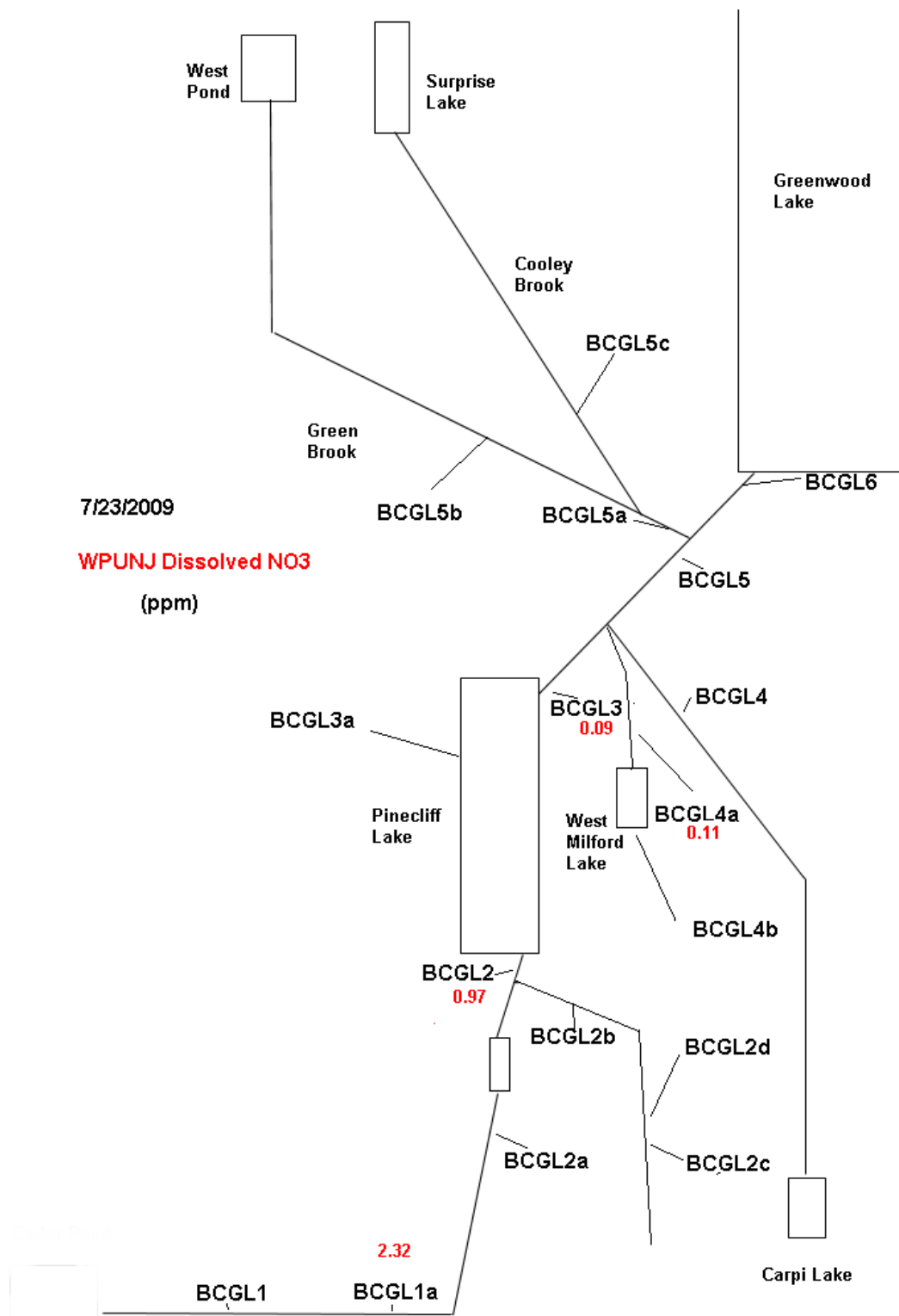


Figure AS25: Summary of Nitrogen Measurements July 23, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

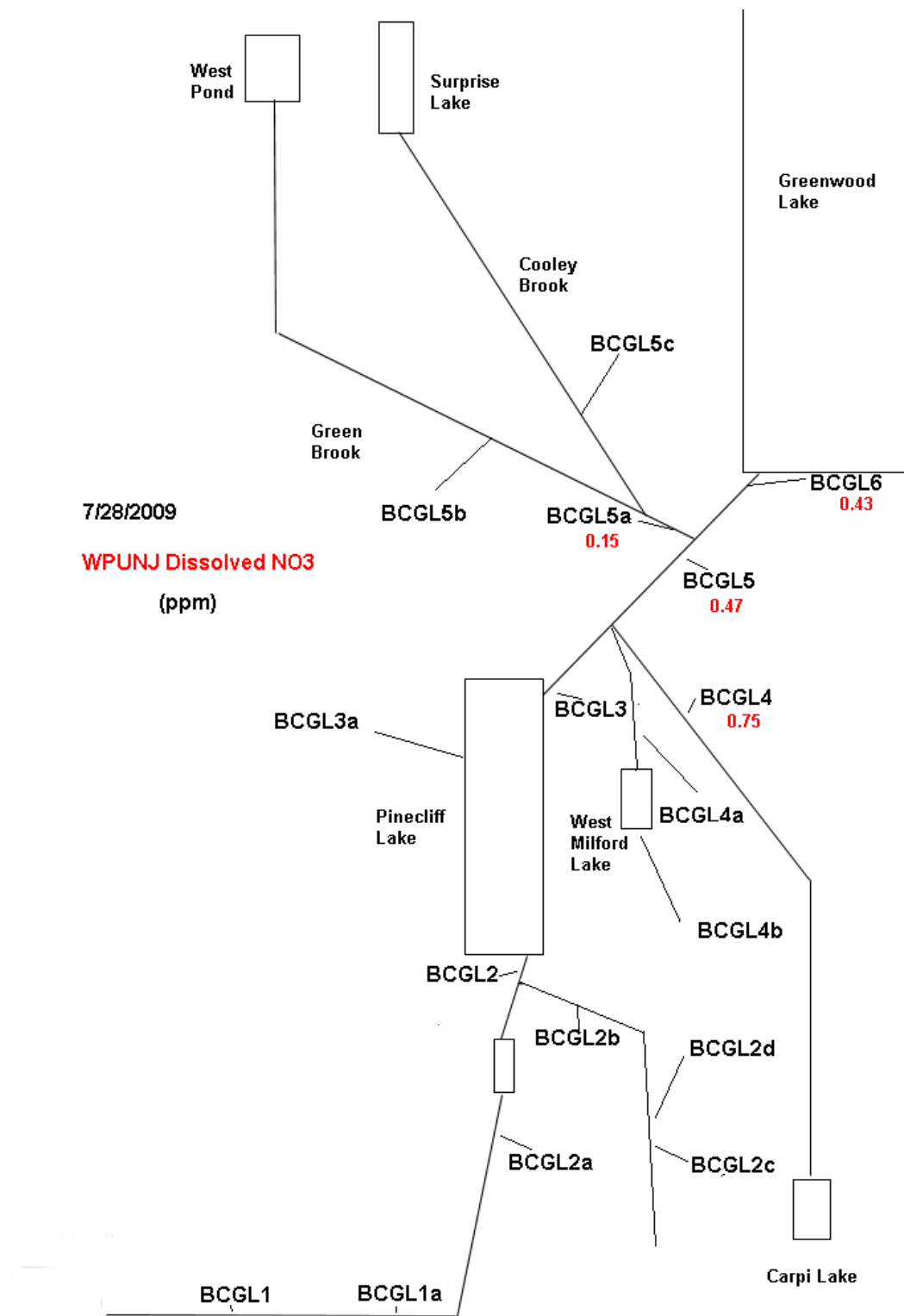


Figure AS26: Summary of Nitrogen Measurements July 28, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

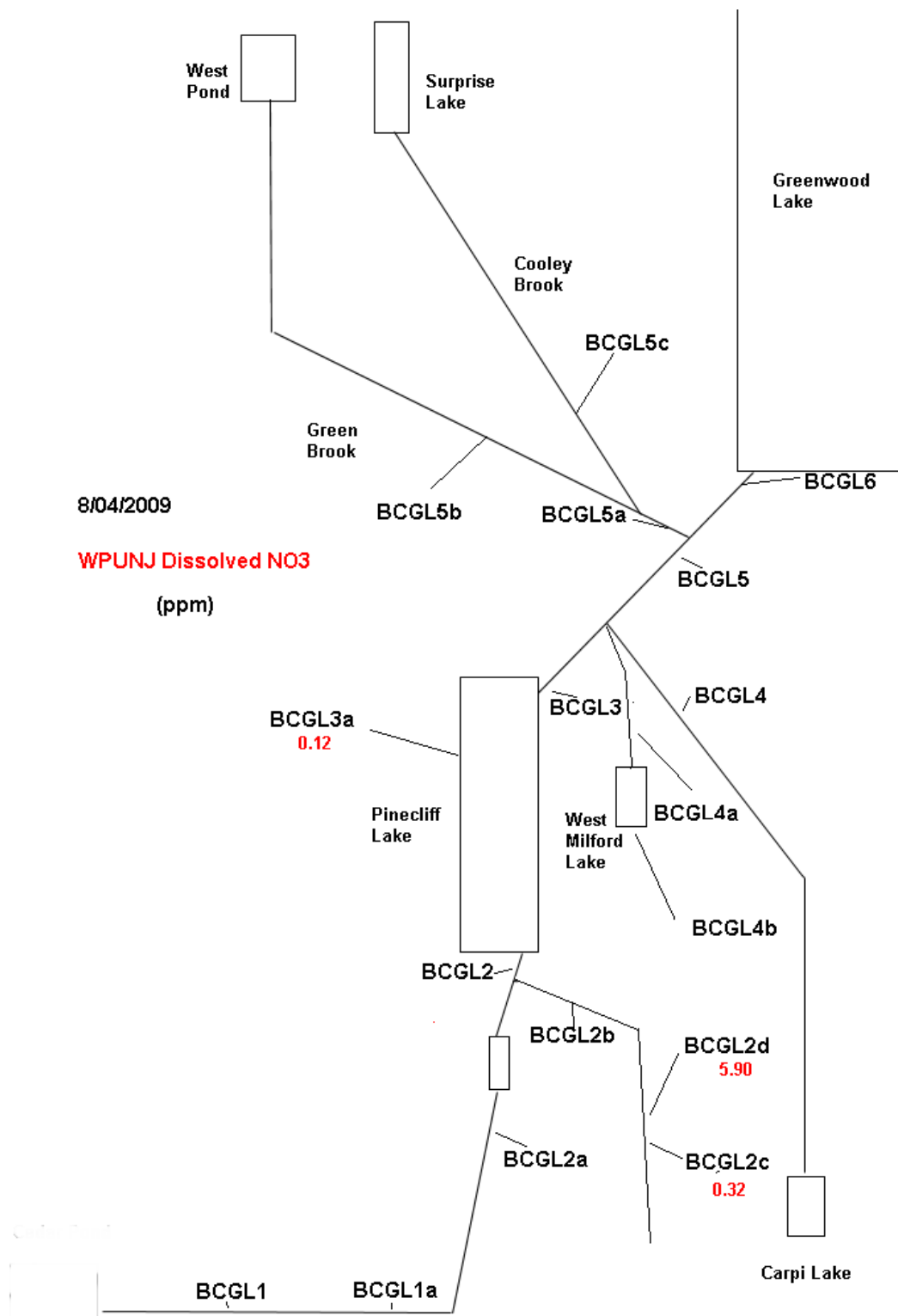


Figure AS27: Summary of Nitrogen Measurements August 4, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

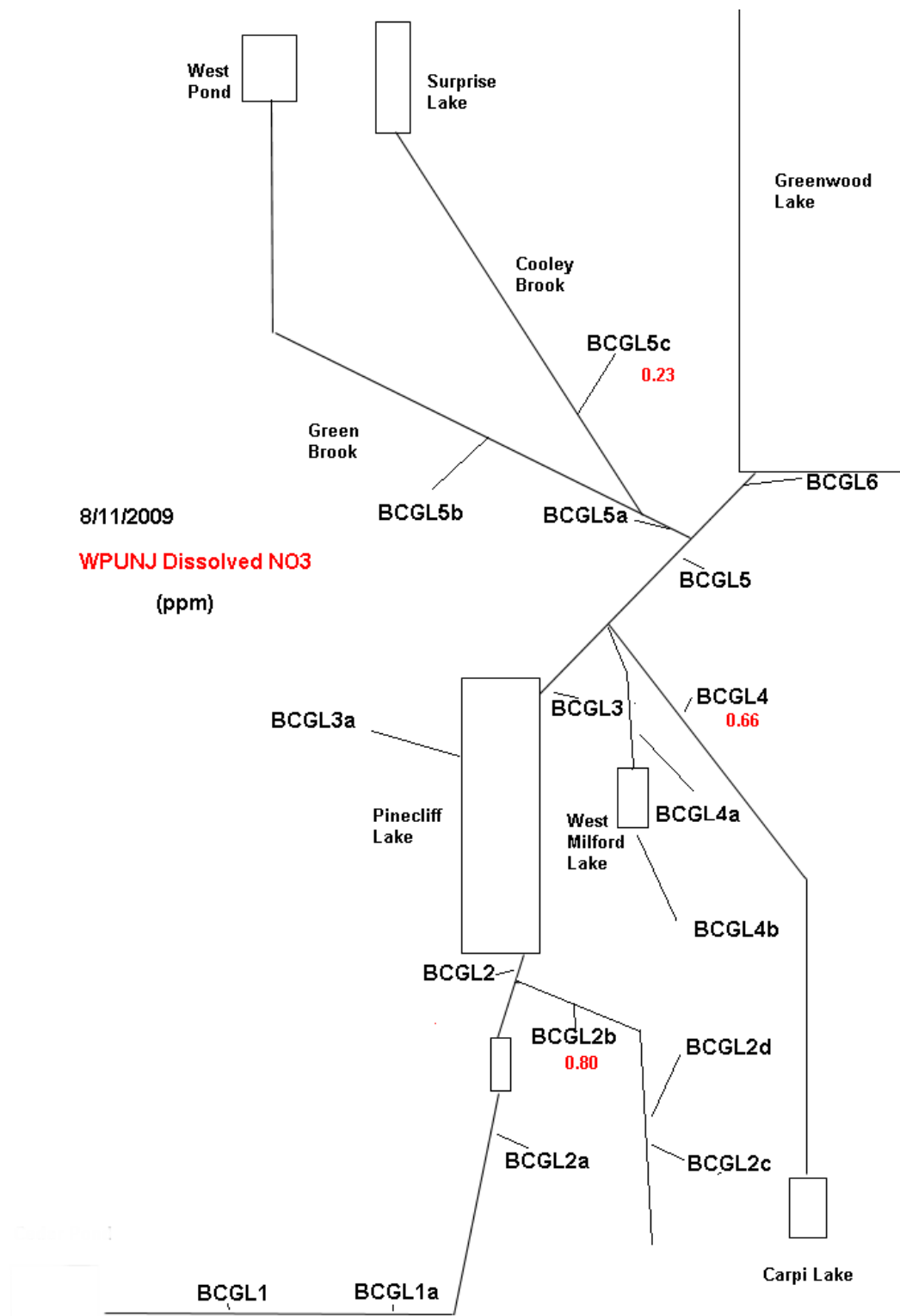


Figure AS28: Summary of Nitrogen Measurements August 11, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

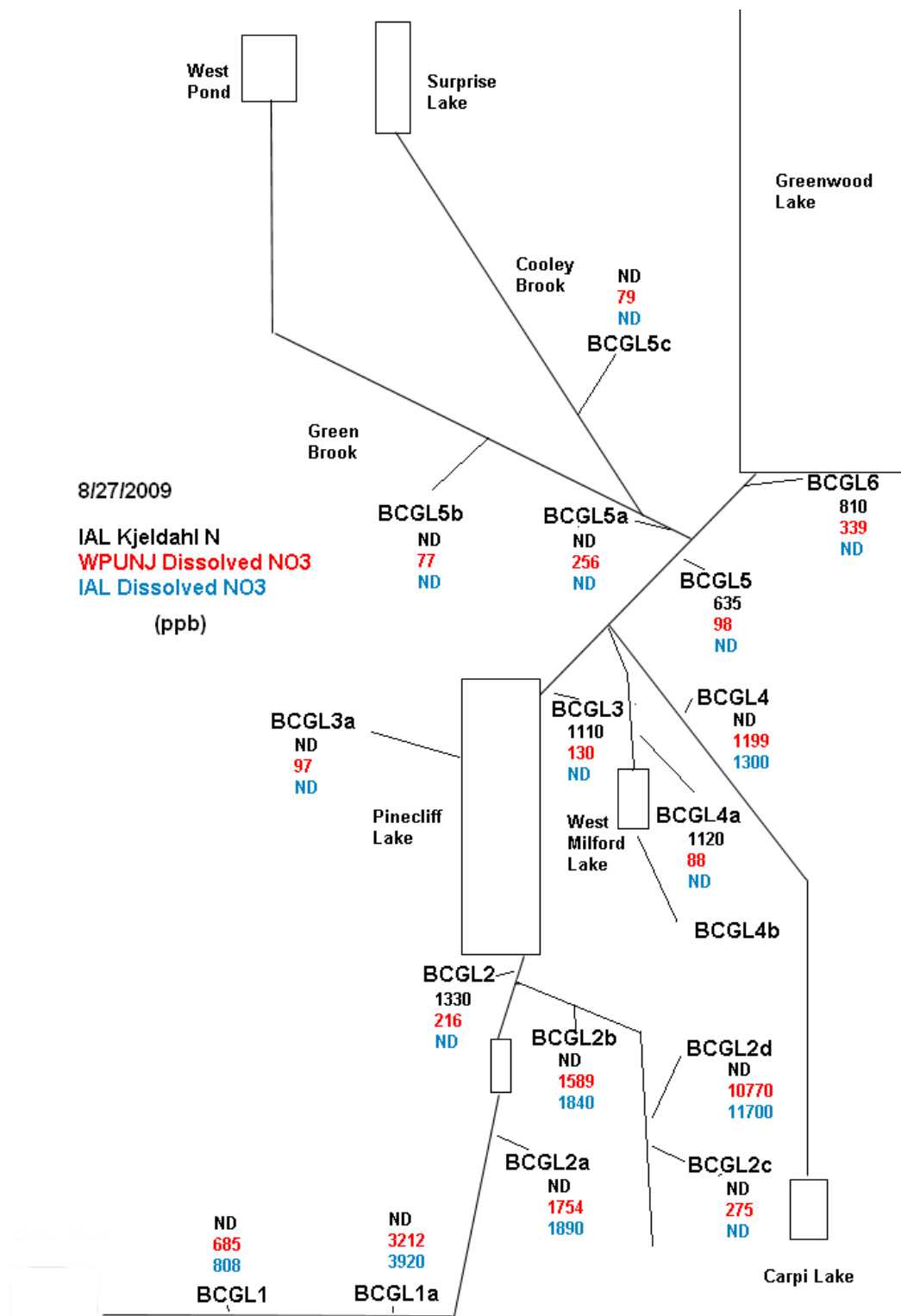


Figure AS29: Summary of Nitrogen Measurements August 27, 2009.



# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

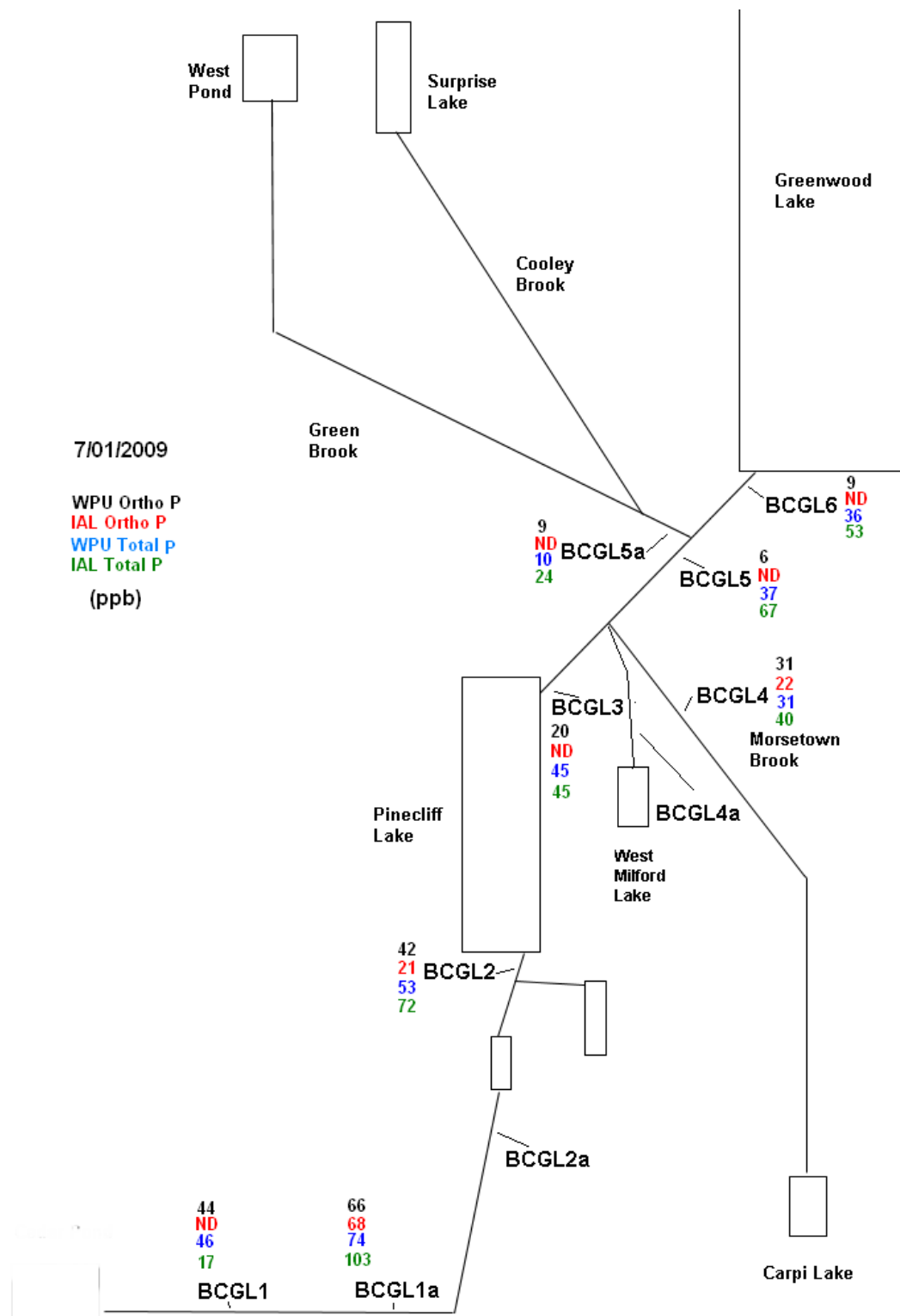


Figure AS30: Summary of Phosphorus Measurements July 1, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

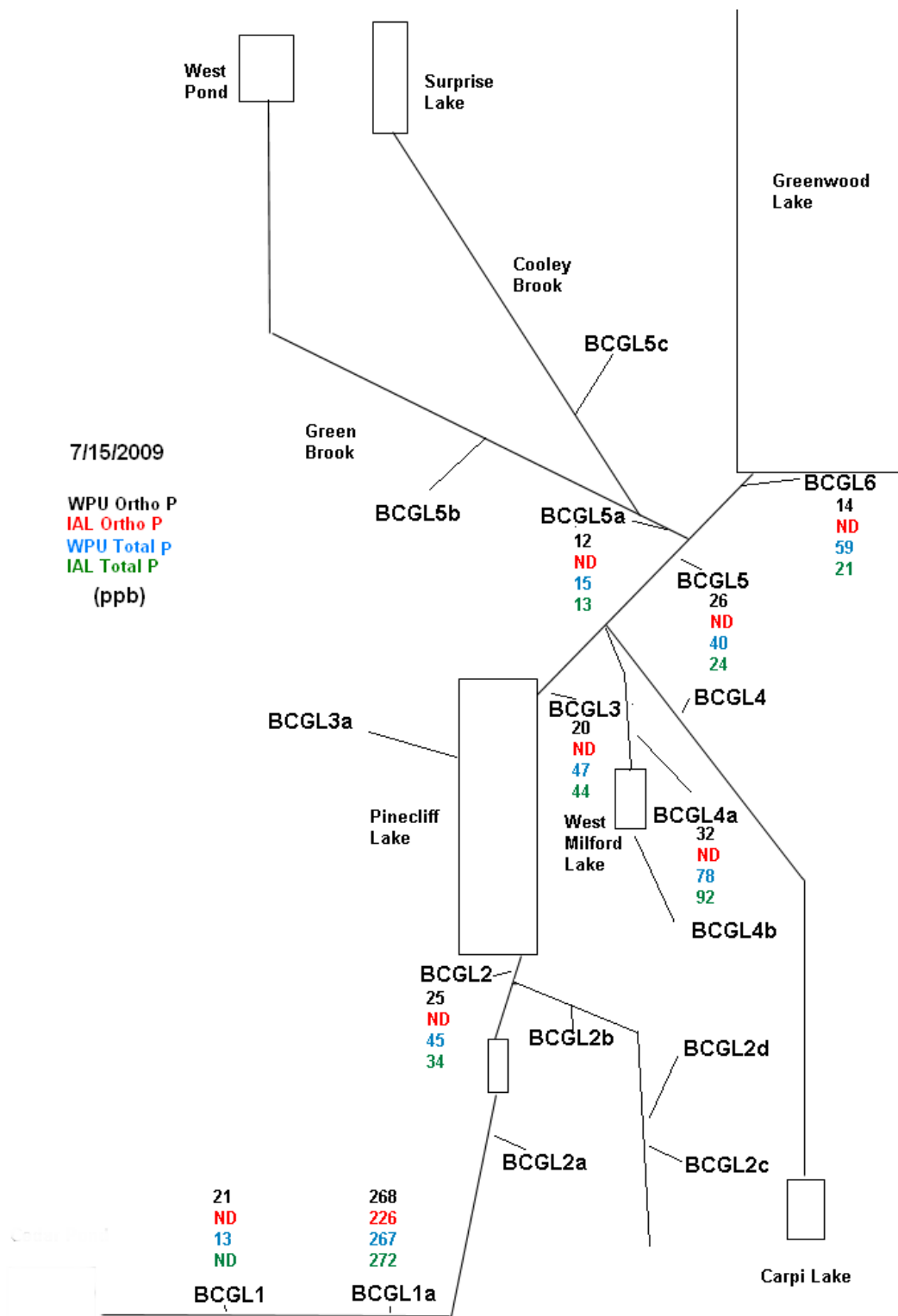


Figure AS31: Summary of Phosphorus Measurements July 15, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

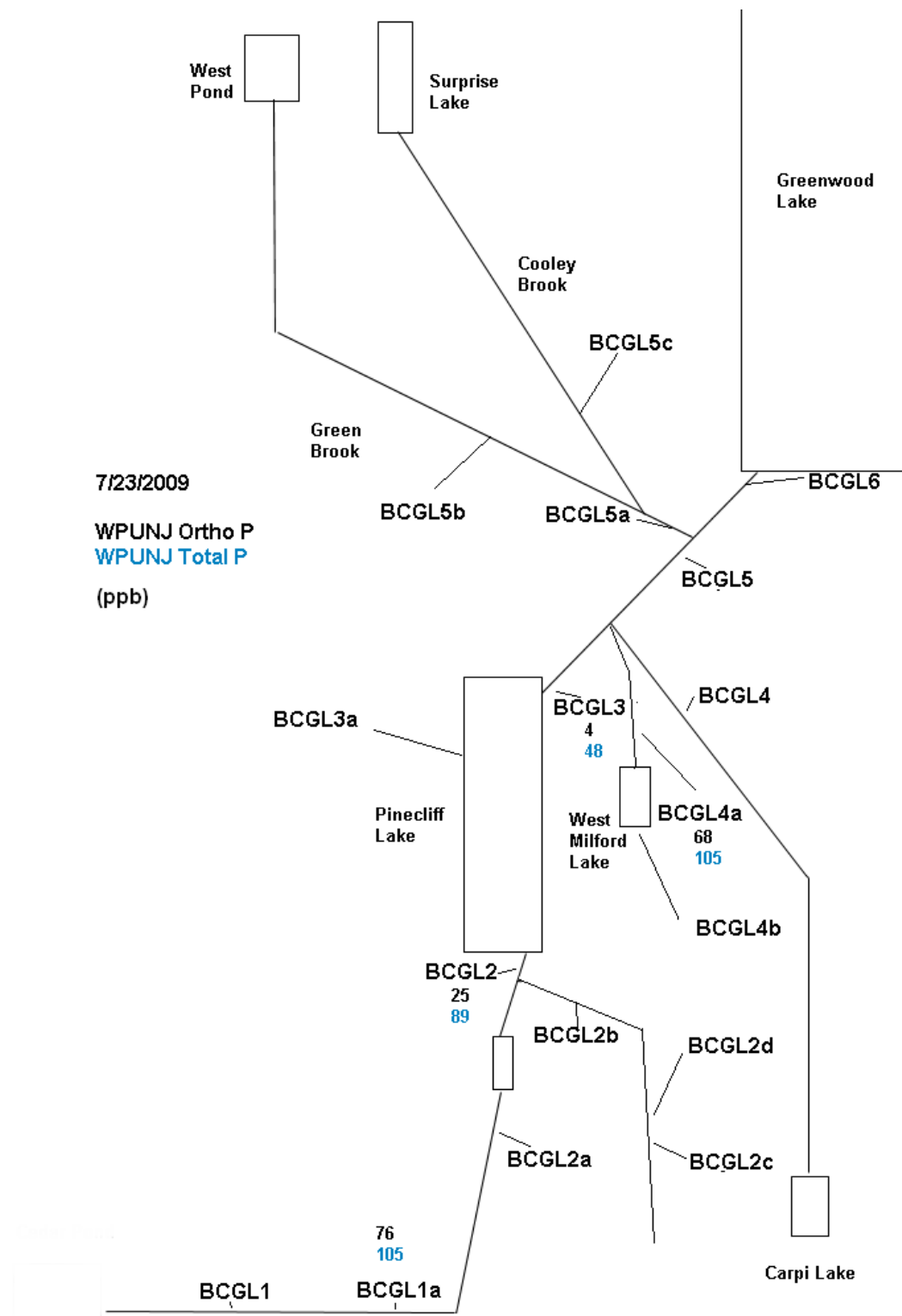


Figure AS32: Summary of Phosphorus Measurements July 23, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

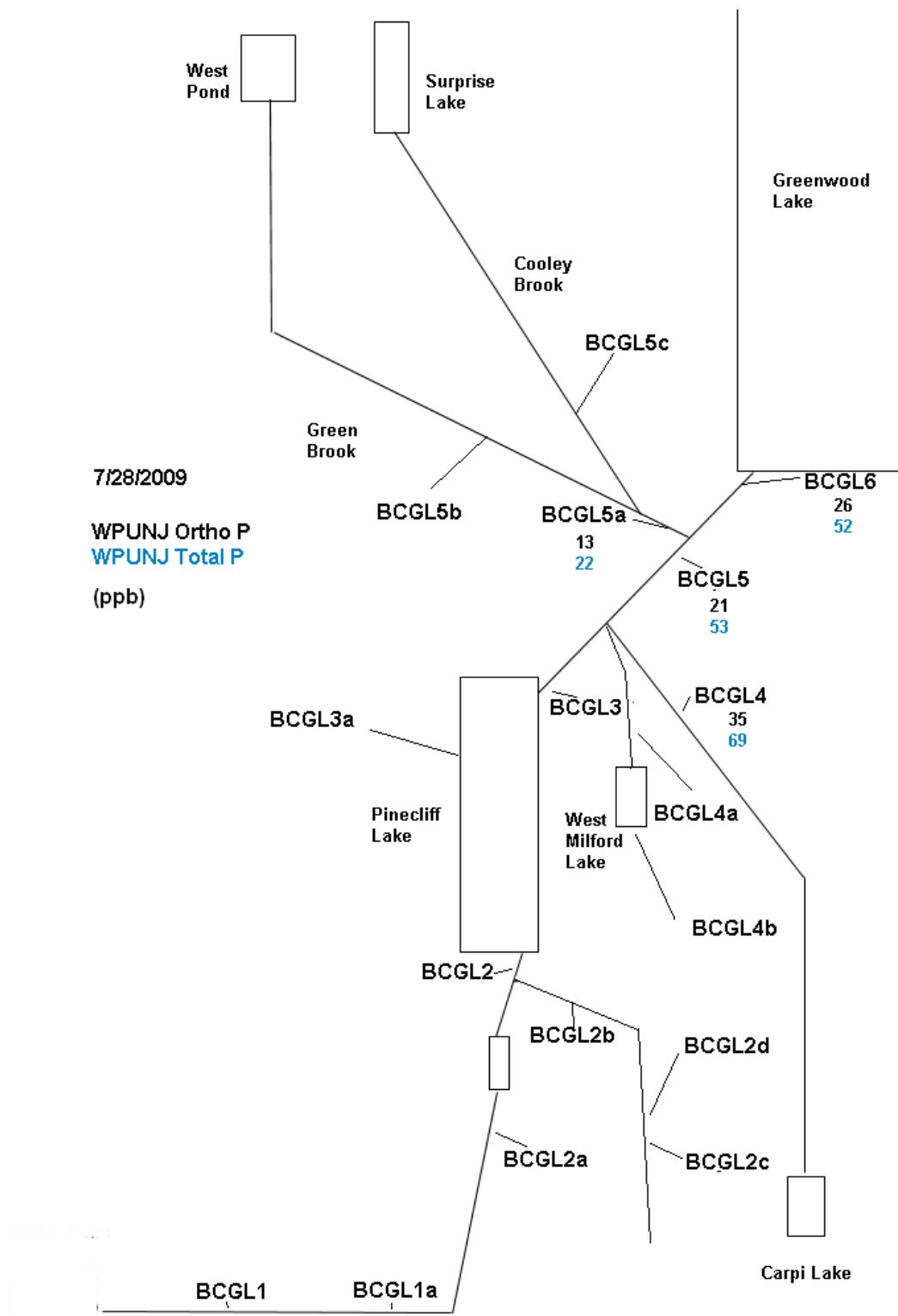


Figure AS33: Summary of Phosphorus Measurements July 28, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

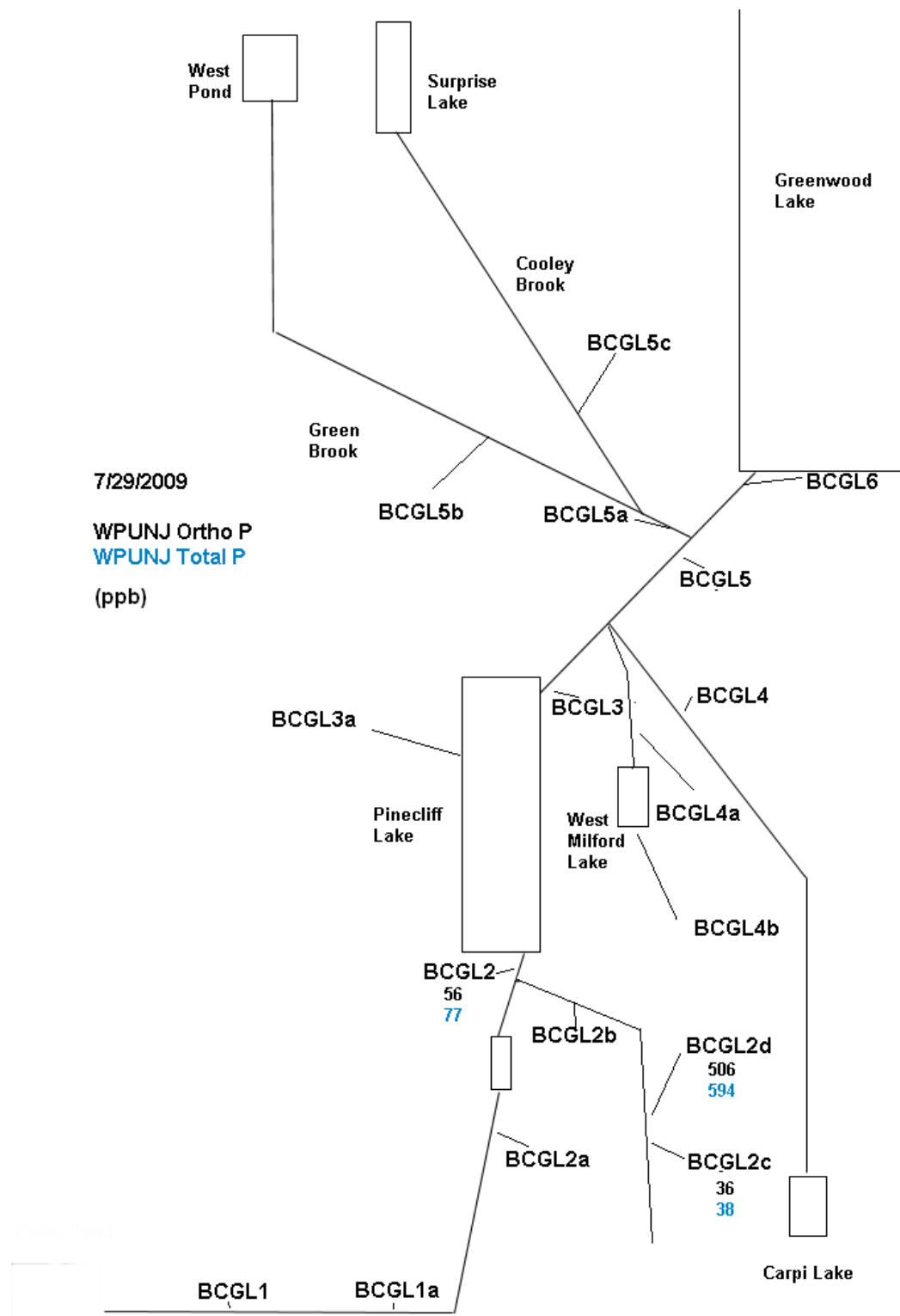


Figure AS34: Summary of Phosphorus Measurements July 29, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

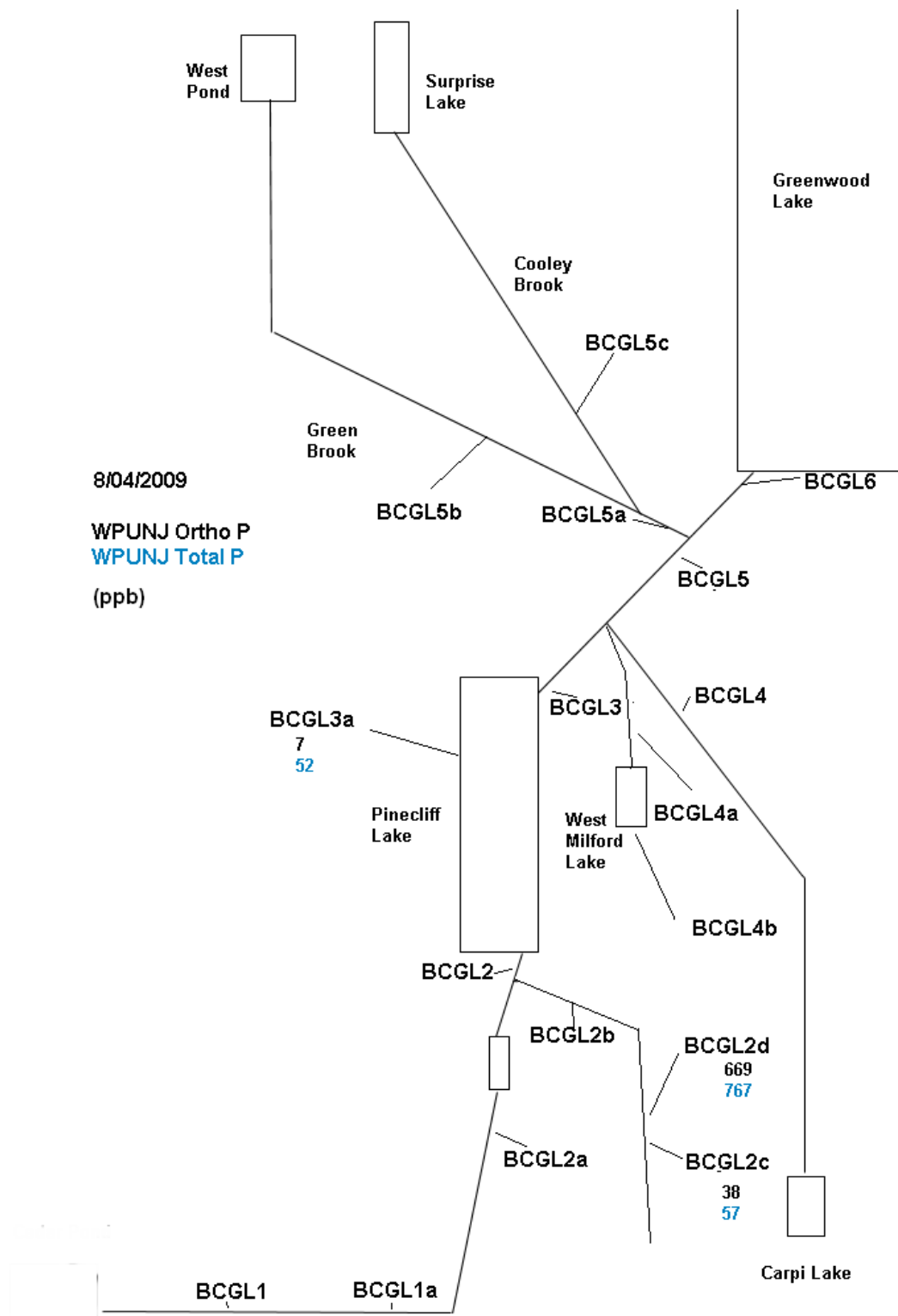


Figure AS35: Summary of Phosphorus Measurements August 4, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

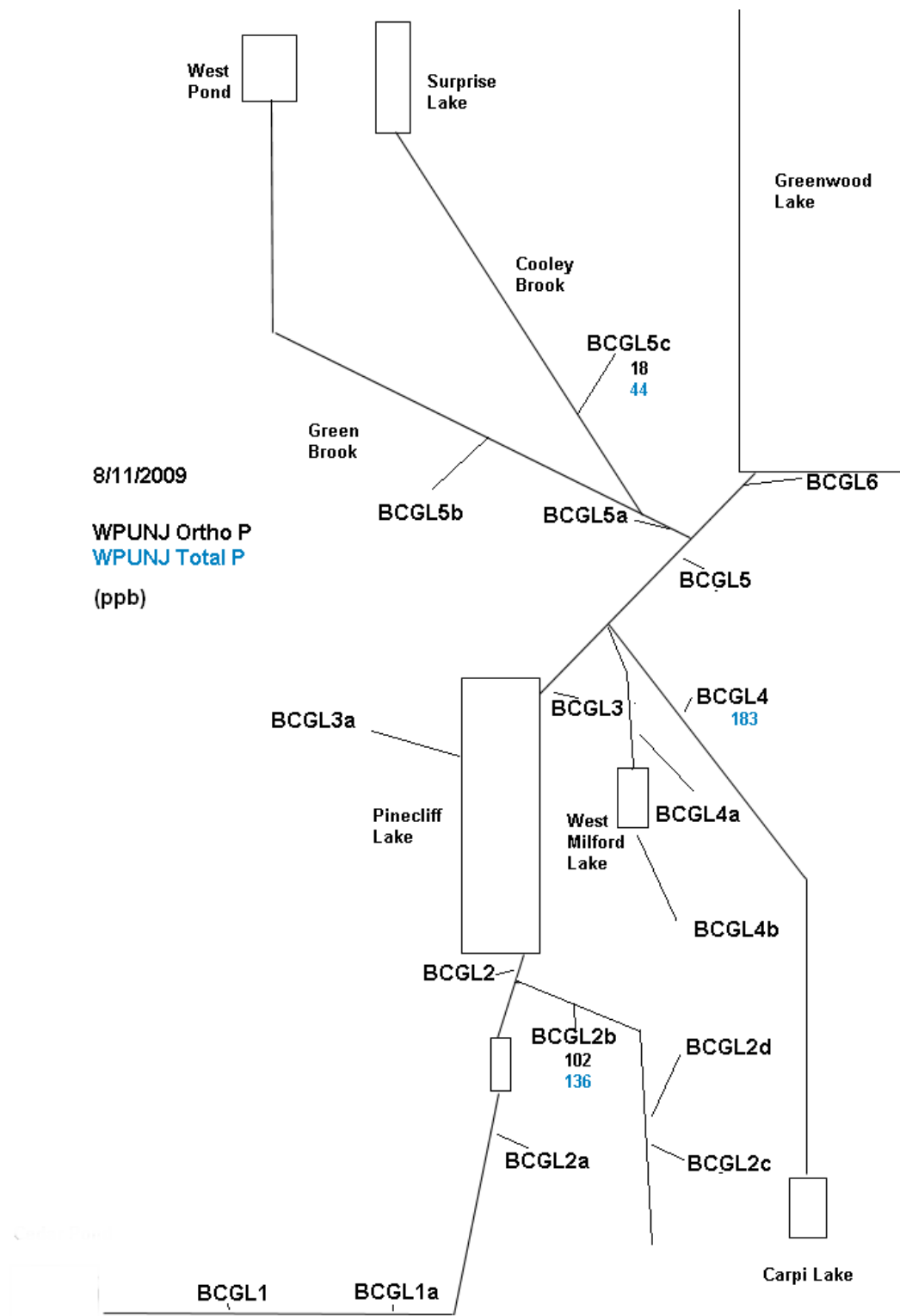


Figure AS36: Summary of Phosphorus Measurements August 11, 2009.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

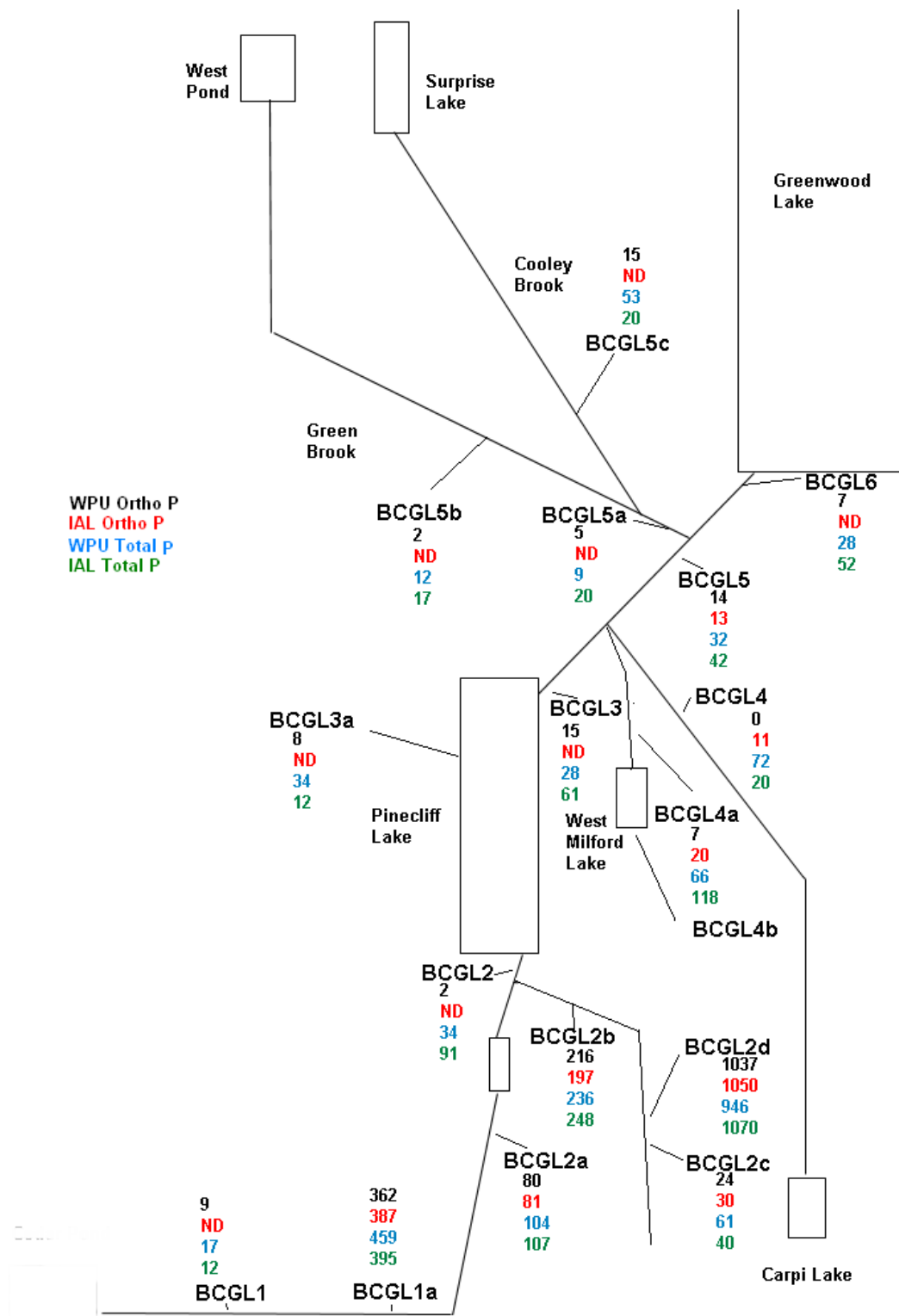


Figure AS37: Summary of Phosphorus Measurements August 27, 2009.



# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

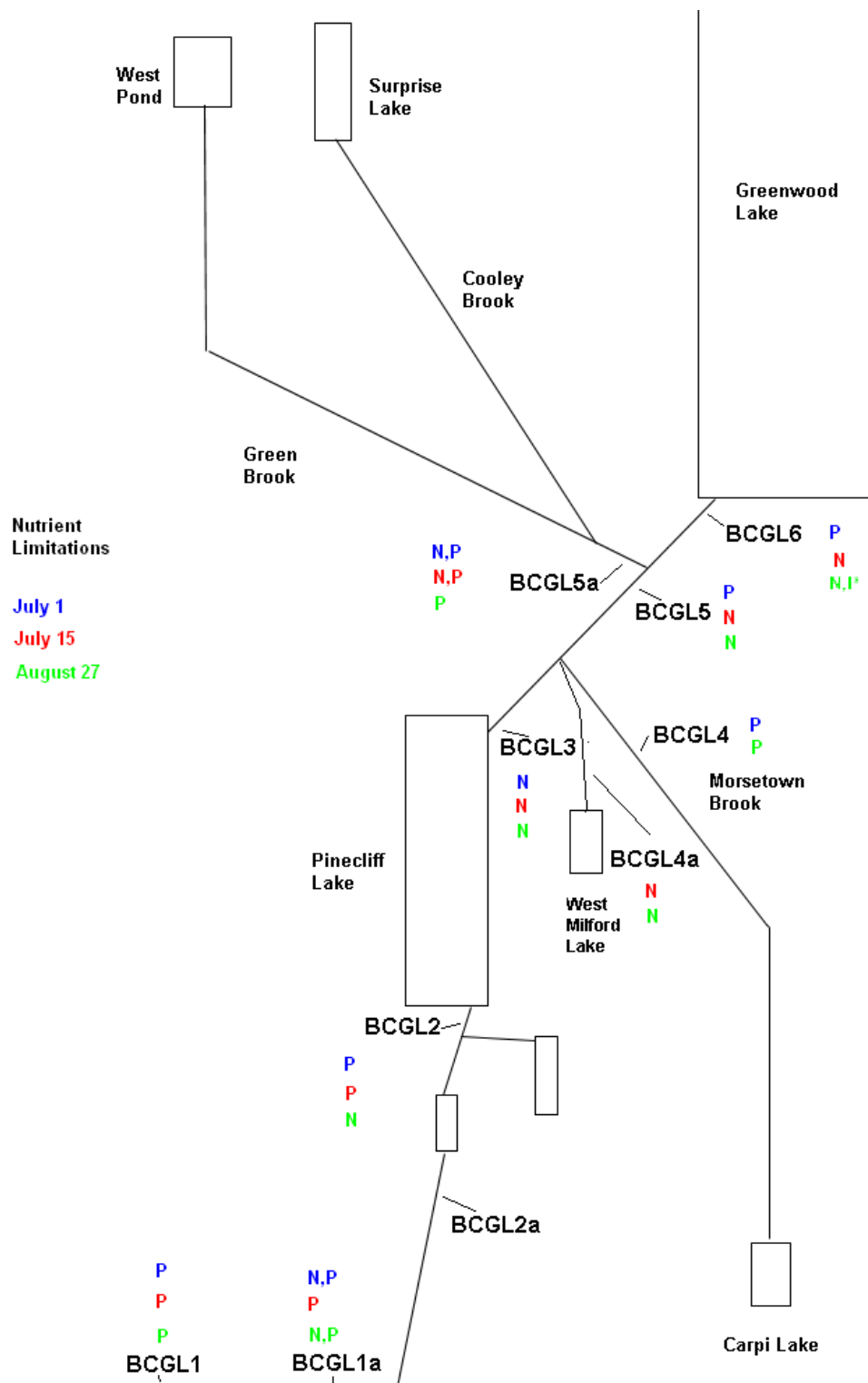


Figure AS38: Nutrient limitations at various stations within the Belcher Creek watershed as measured on three different days during the summer of 2009.

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

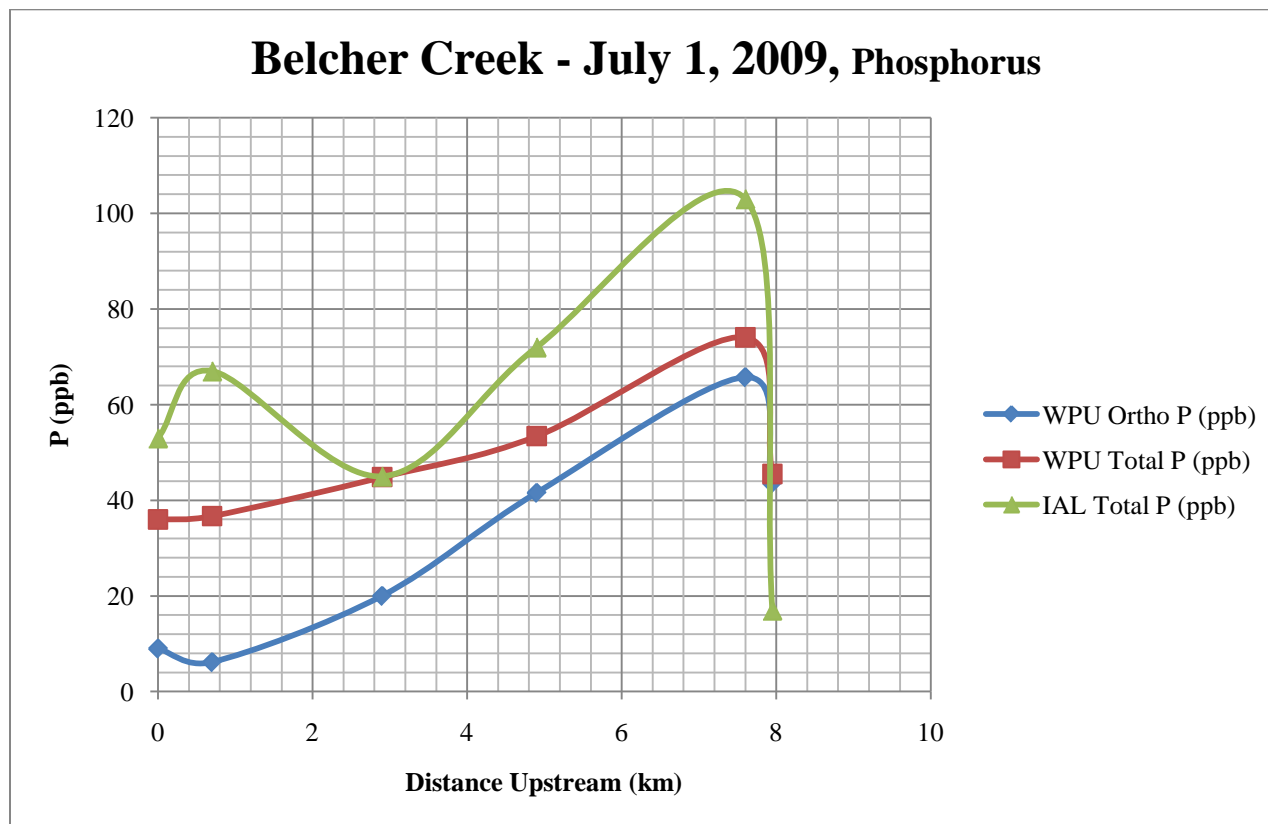


Figure AP39: P profile along main channel of Belcher Creek, July 1, 2009.

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

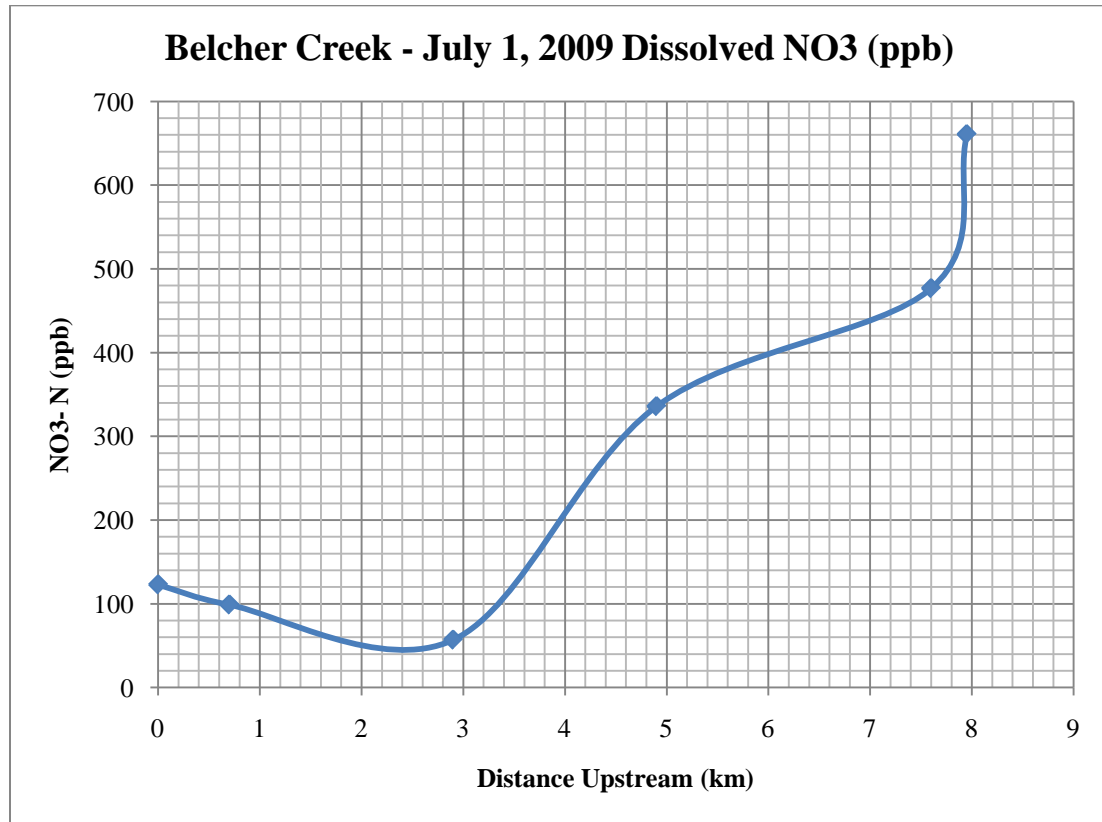


Figure AP40: N profile along main channel of Belcher Creek, July 1, 2009.

## V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

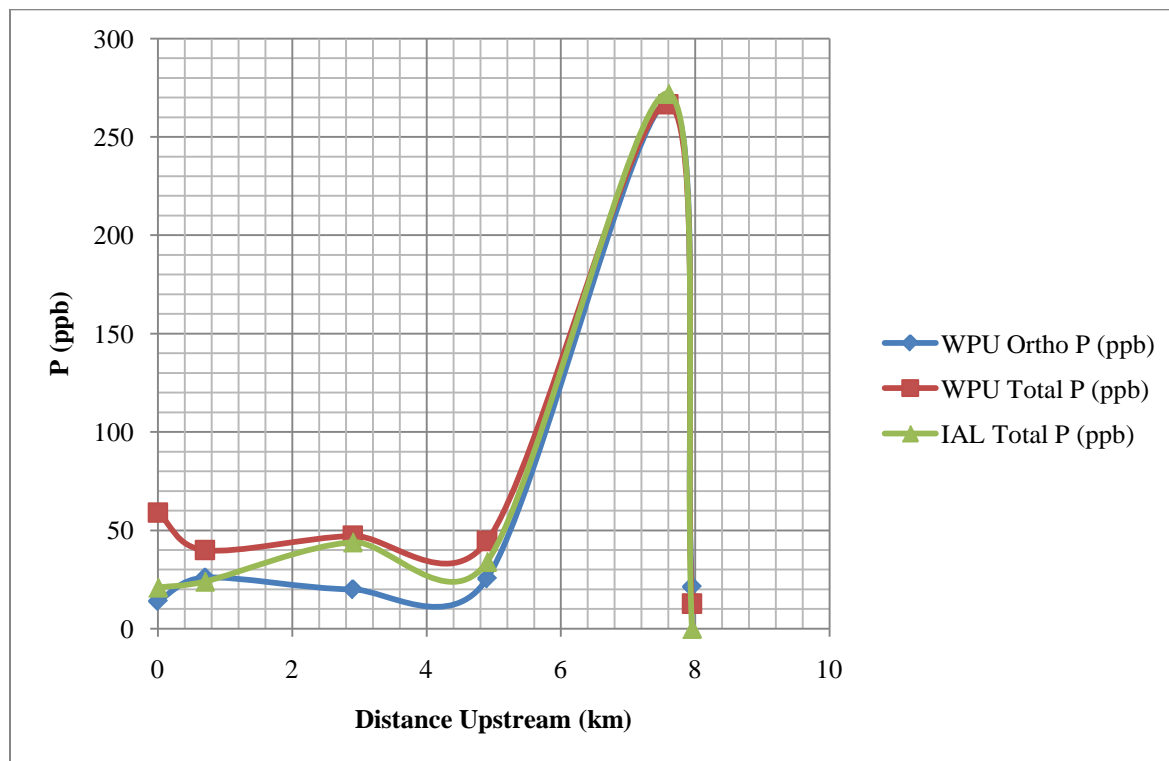


Figure AP41: P profile along main channel of Belcher Creek, July 15, 2009.

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

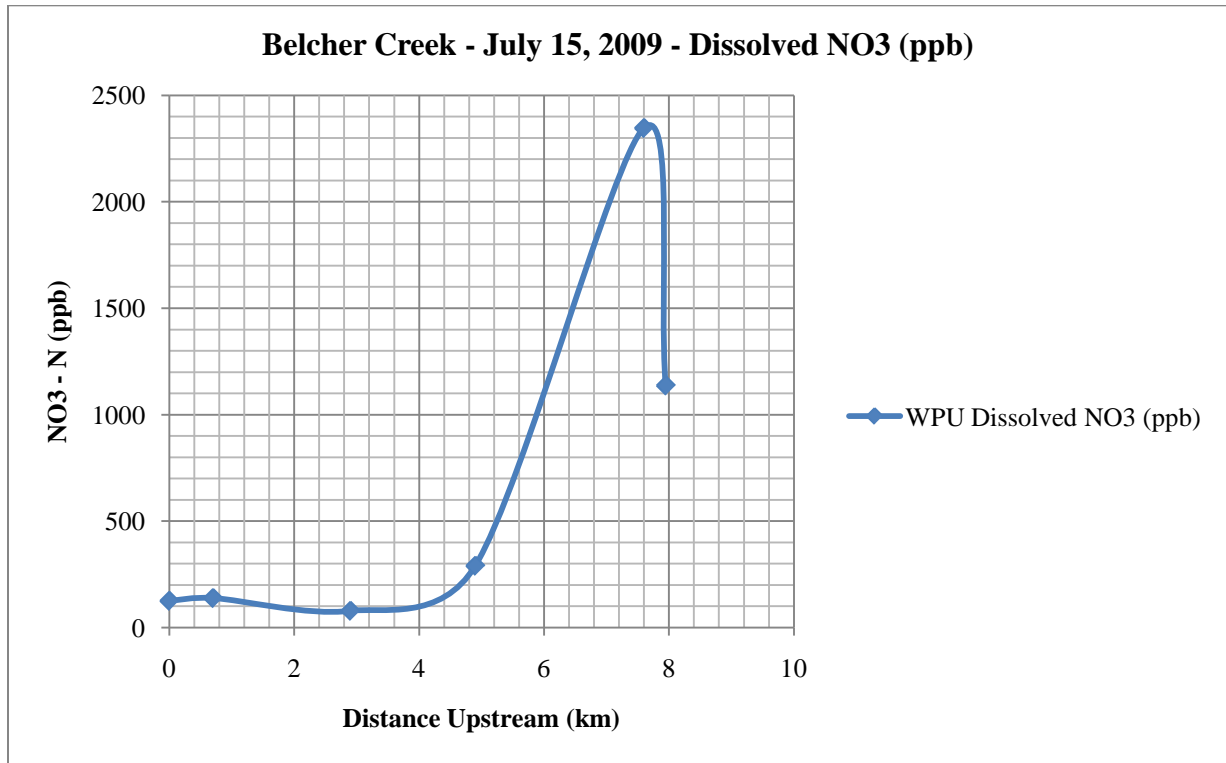


Figure AP42: N profile along main channel of Belcher Creek, July 15, 2009.

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

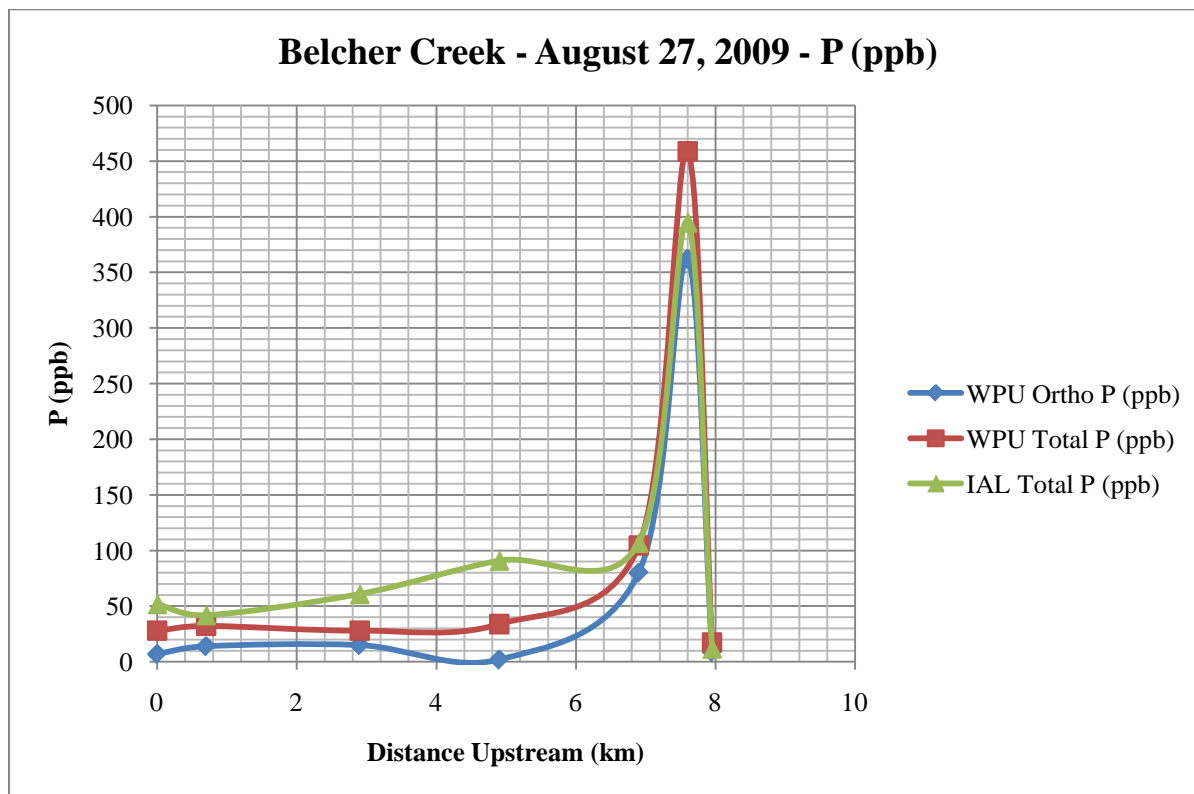


Figure AP43: P profile along main channel of Belcher Creek, August 27, 2009.

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

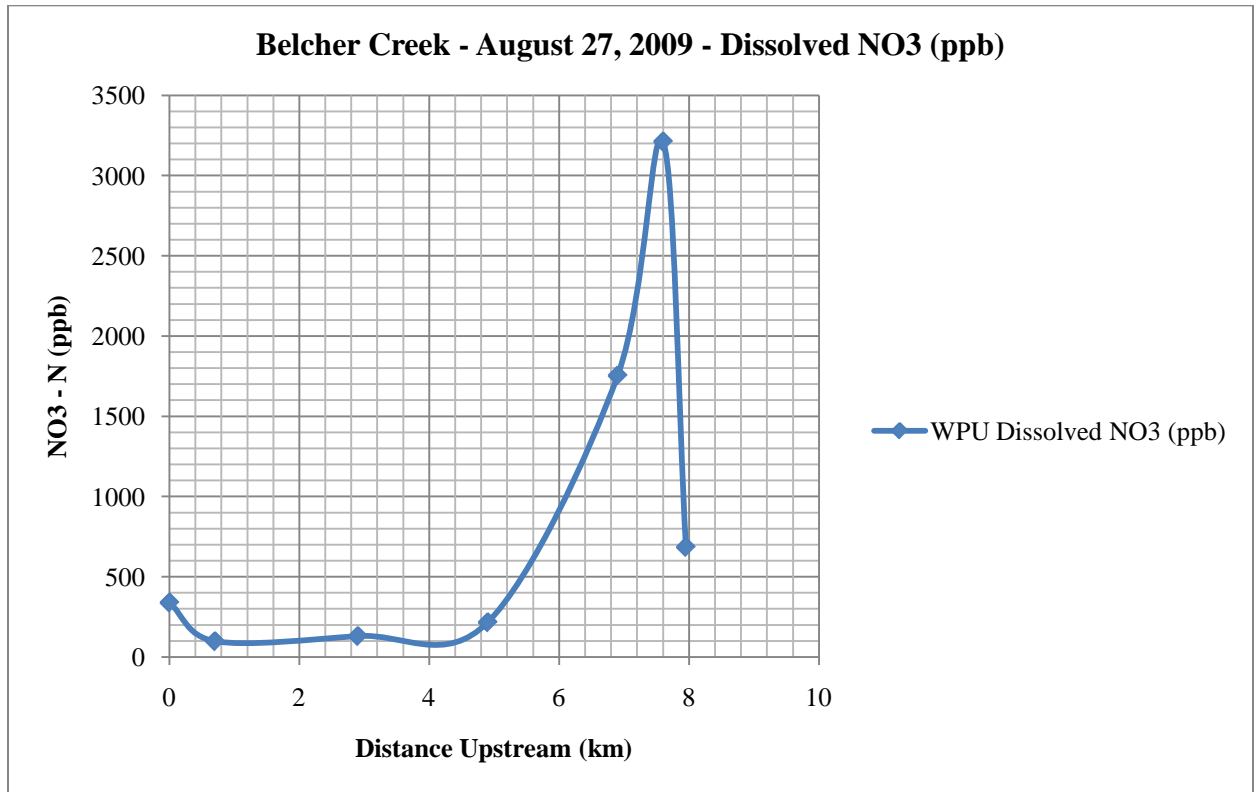
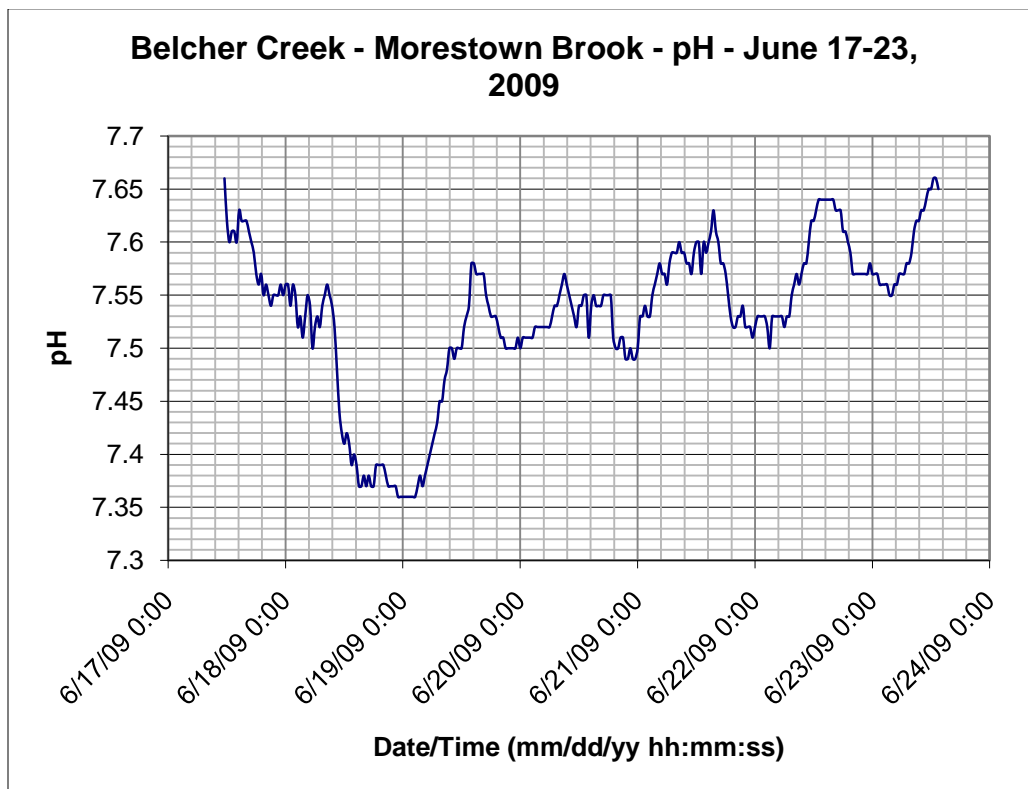
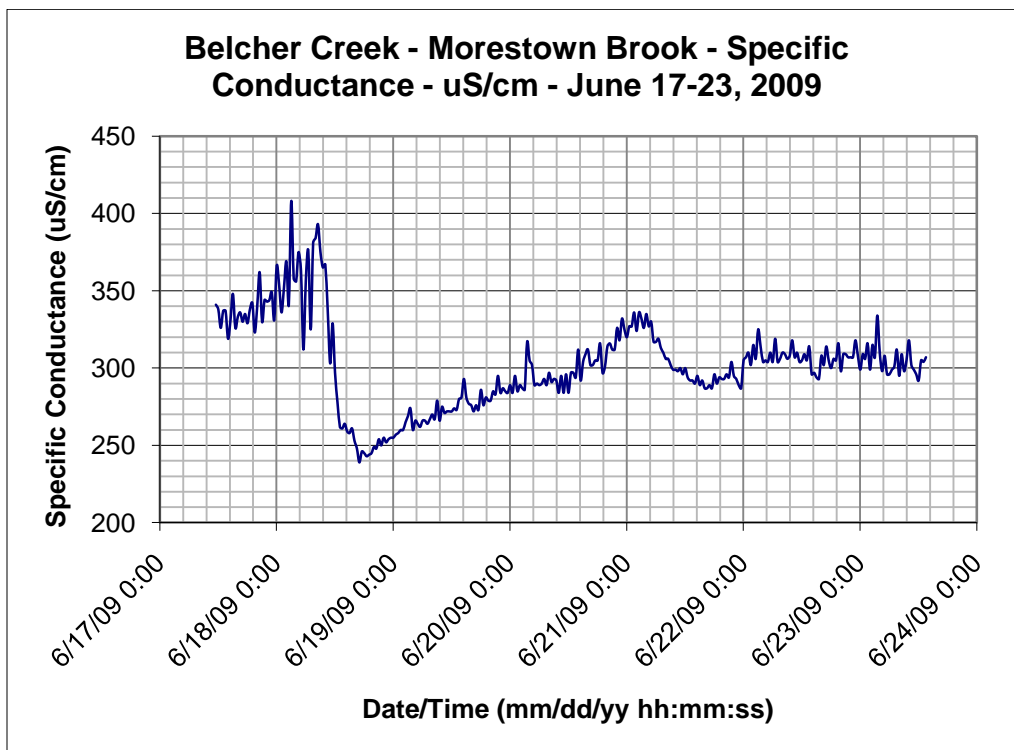


Figure AP44: N profile along main channel of Belcher Creek, August 27, 2009.

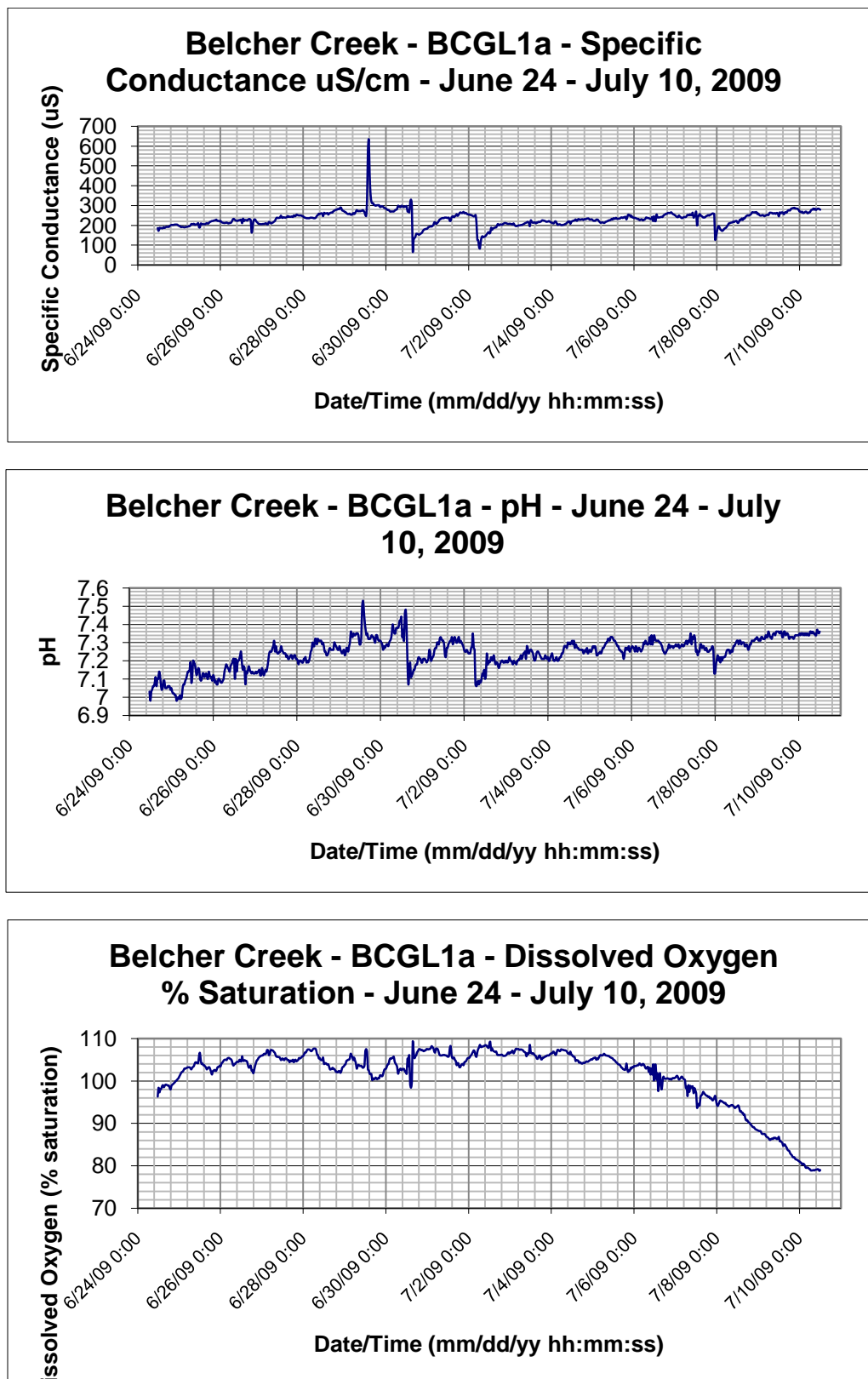
V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED



Figures A45a, b: Selected sonde measurements – June 17-23, 2009, BCGL4

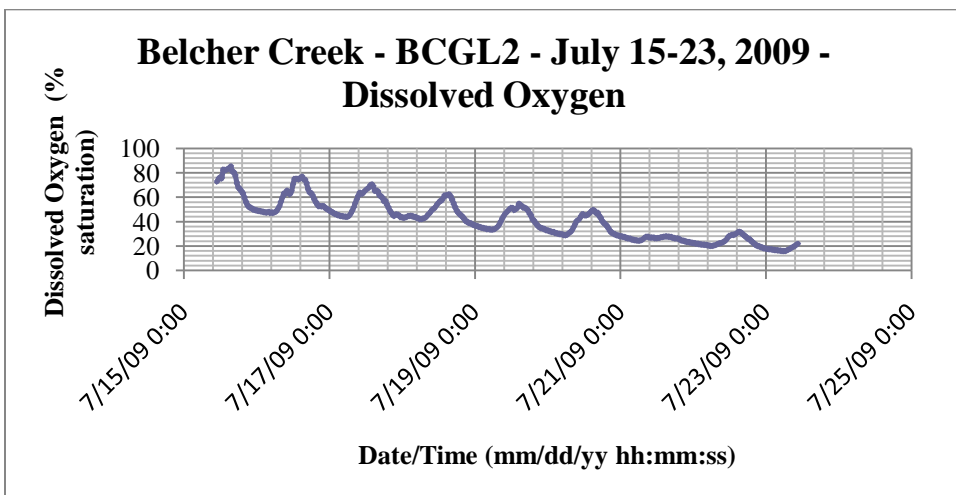
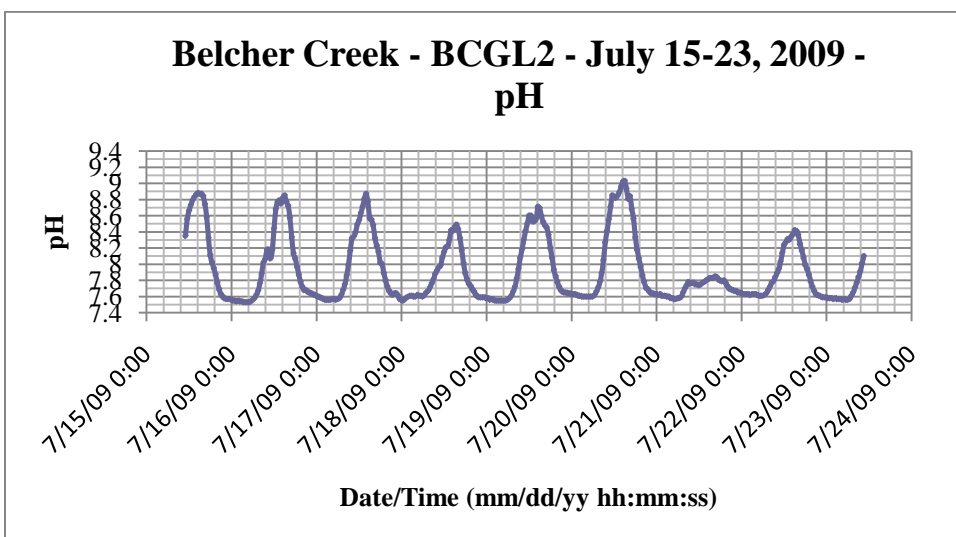
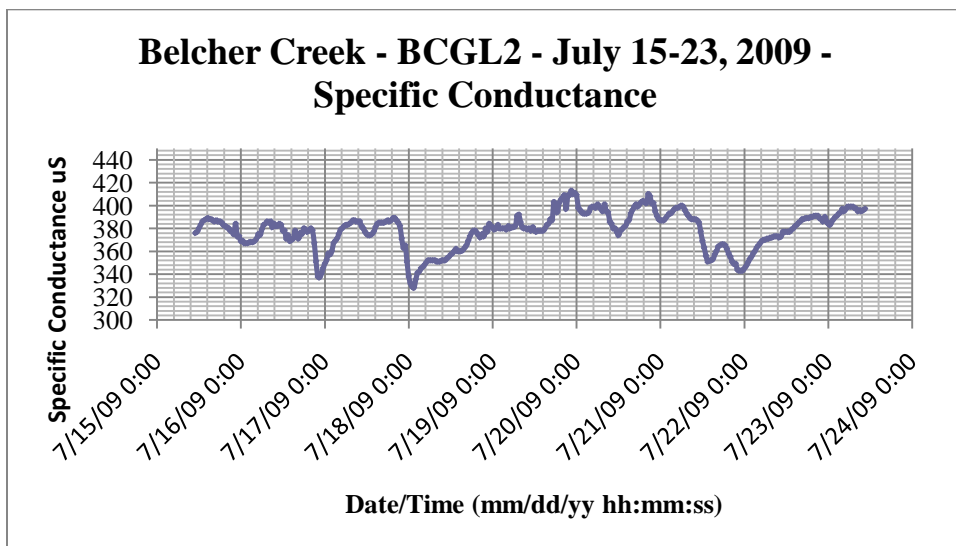


V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED



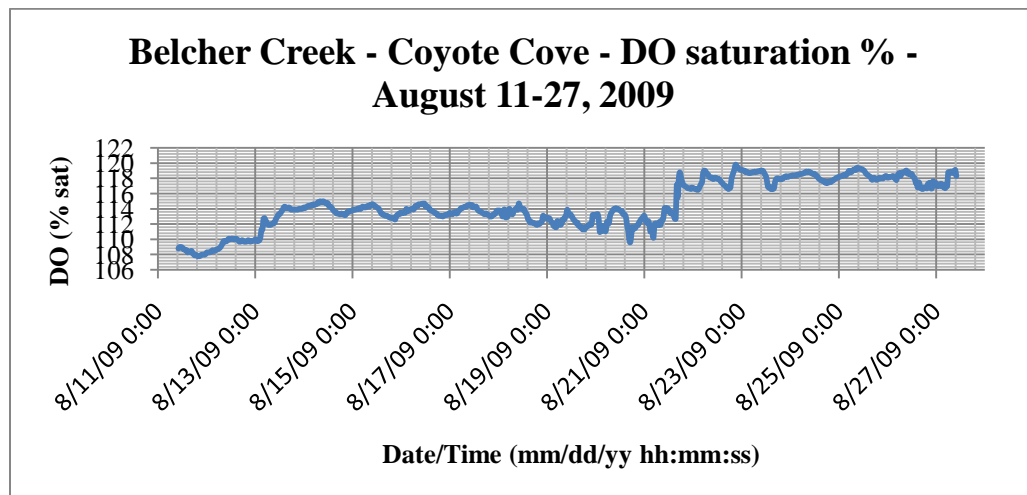
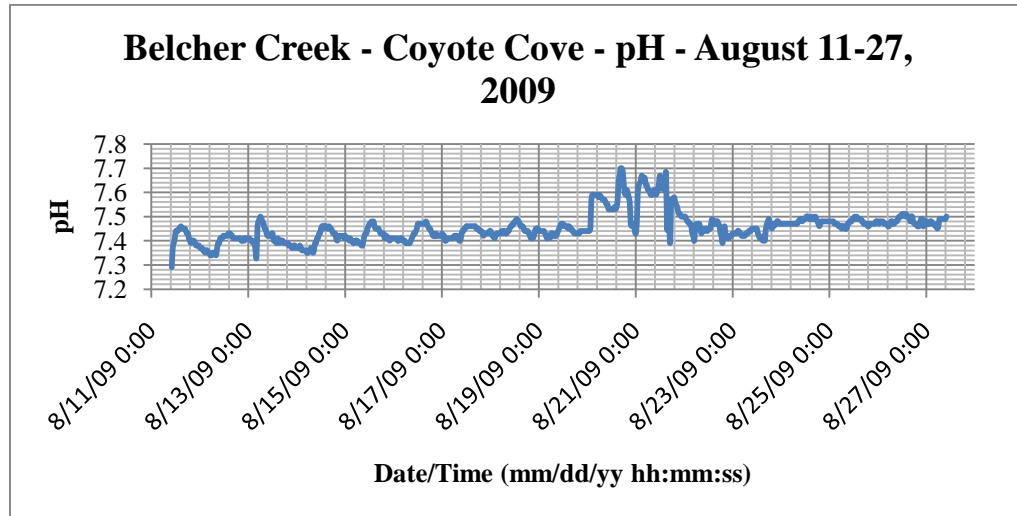
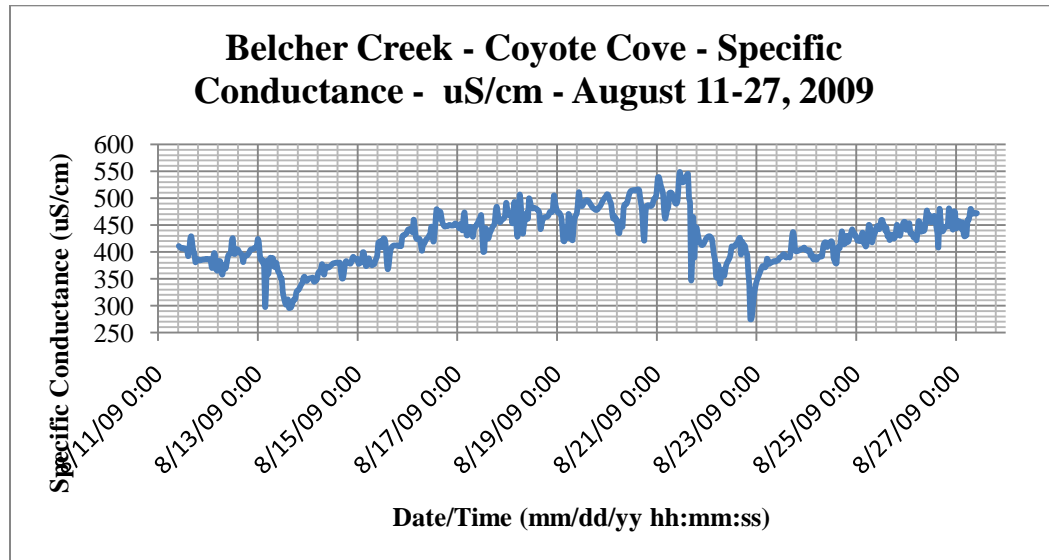
Figures A46a, b, c: Selected sonde measurements – June 24 – July 10, 2009, BCGL1a

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED



Figures A47a, b, c: Selected sonde measurements – July 15- 23, 2009, BCGL2

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED



Figures A48a, b, c: Selected sonde measurements – August 11-27, 2009, BCGL2a

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

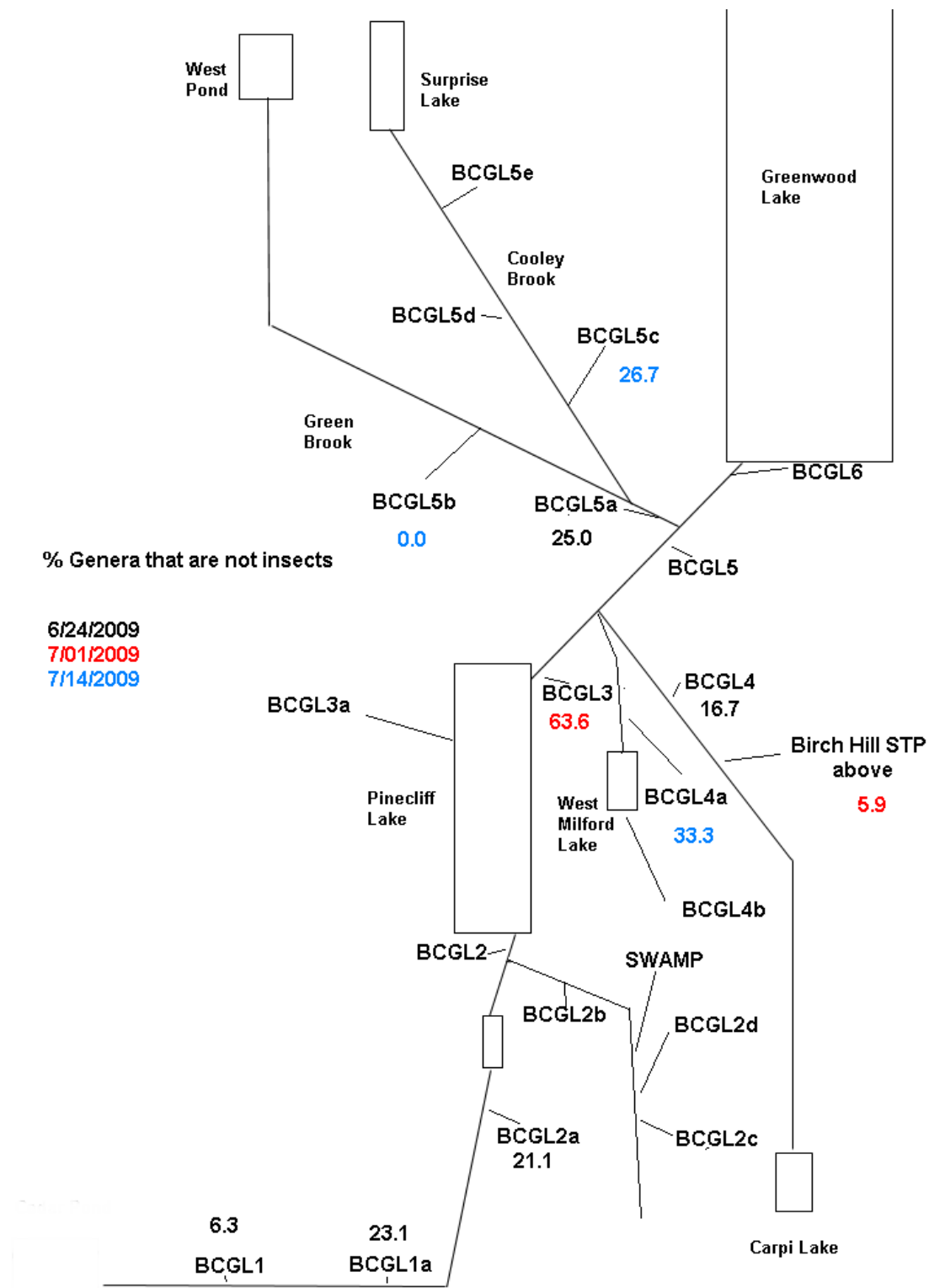


Figure AS49: % Genera that are not insects

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

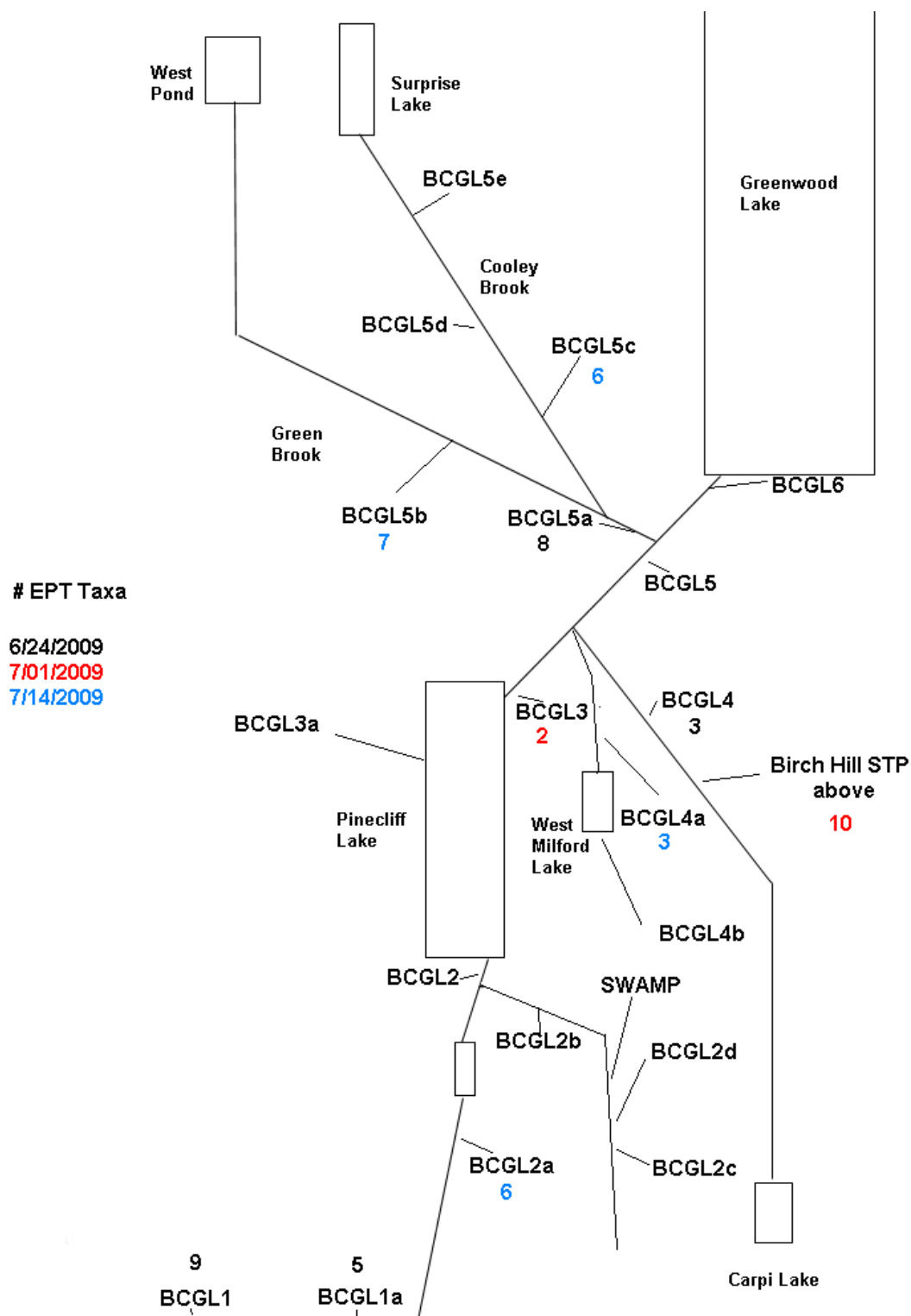


Figure AS50: # EPT taxa

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

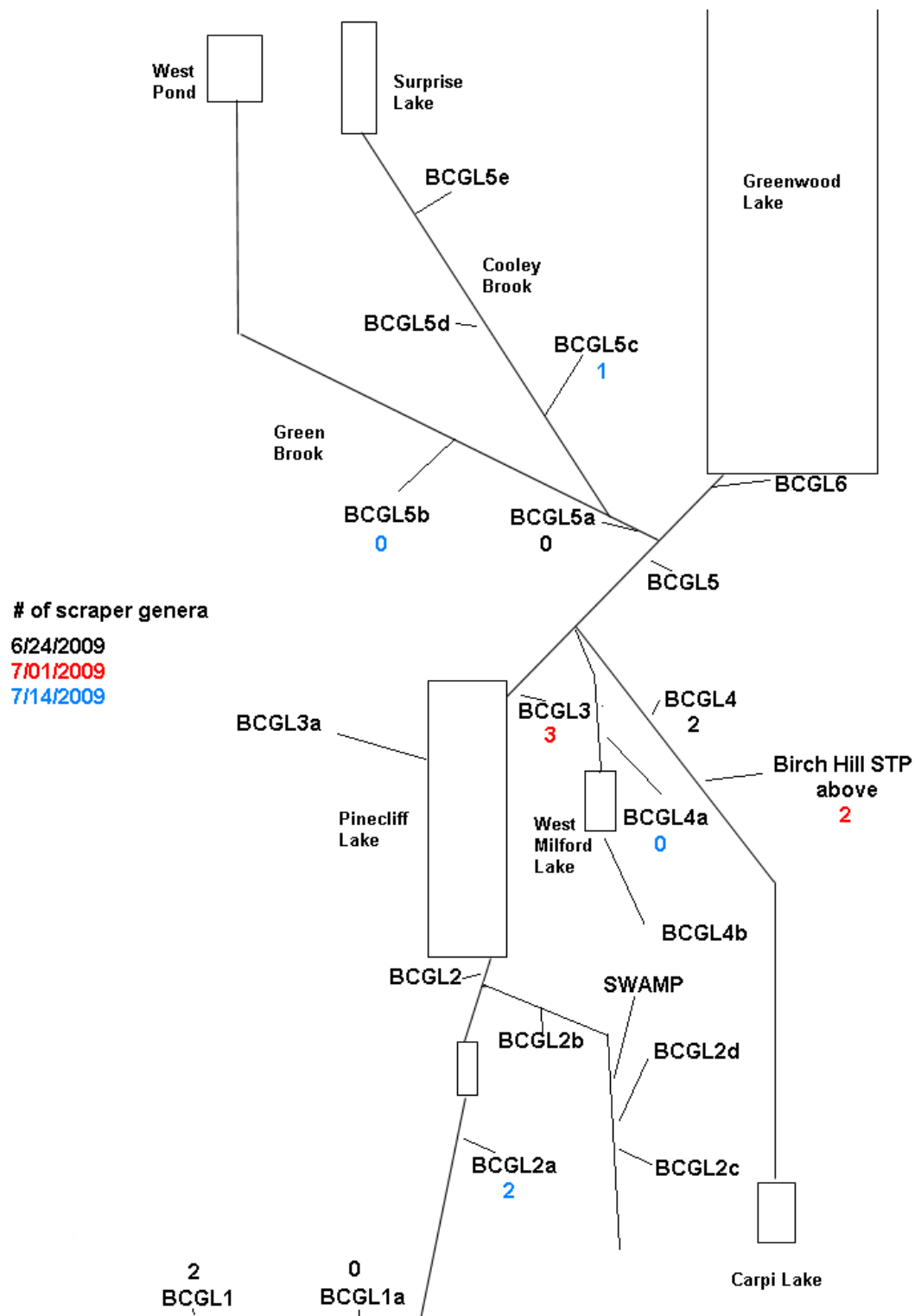


Figure AS51: # Scrapper genera.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

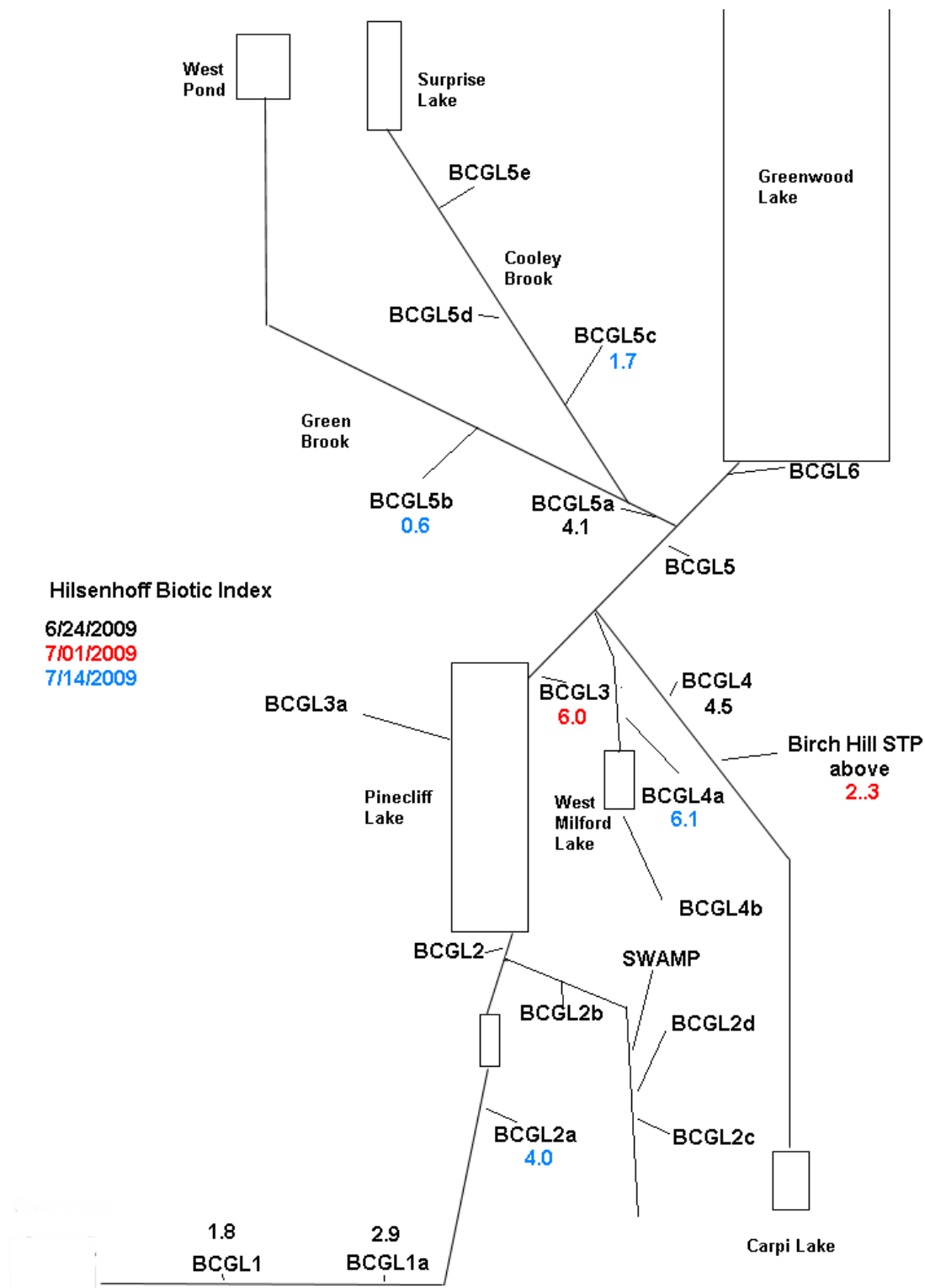


Figure AS52: Hilsenhoff Biotic Index.

# V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK IN THE GREENWOOD LAKE WATERSHED

Belcher Creek/Greenwood Lake

WPUNJ data - 2009

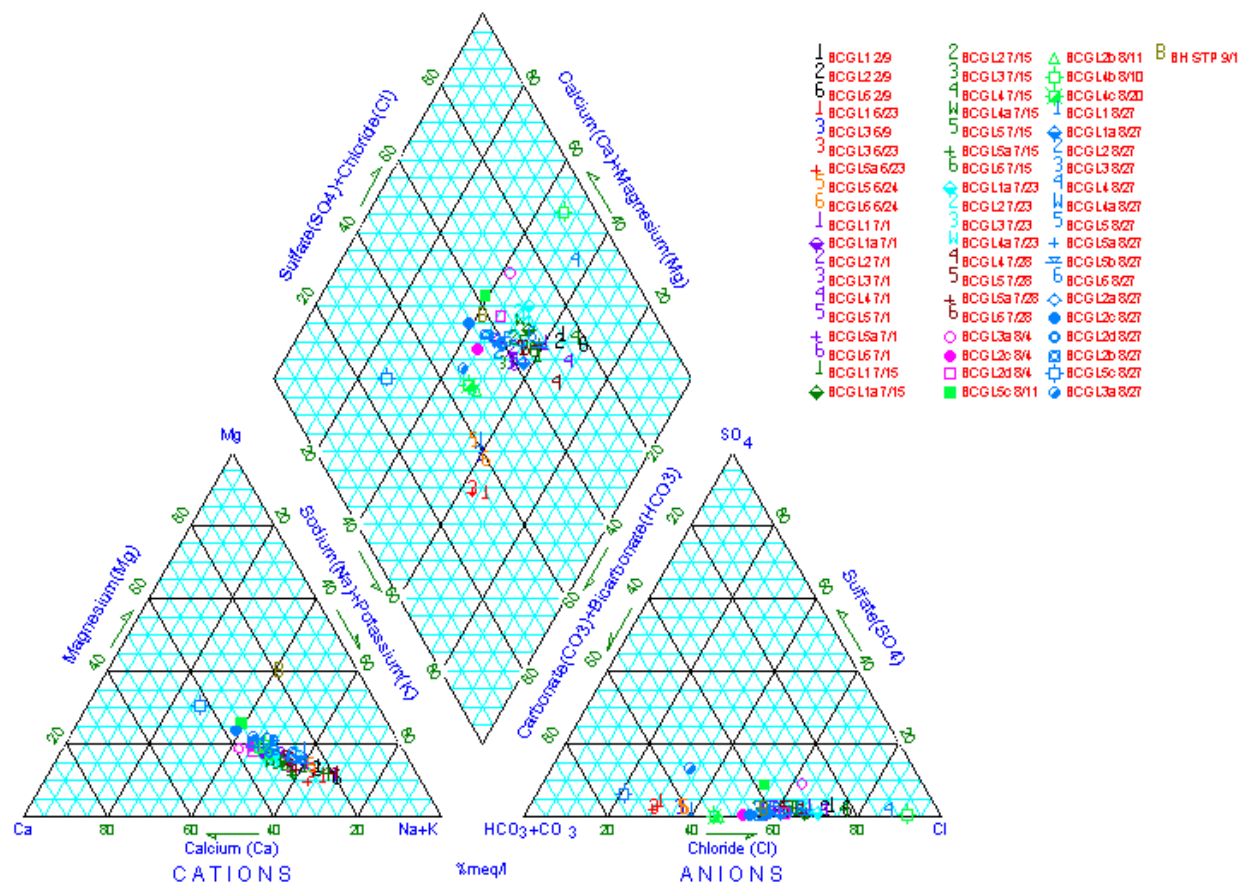


Figure A53: Tri-linear diagram summarizing major dissolved ions.



V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

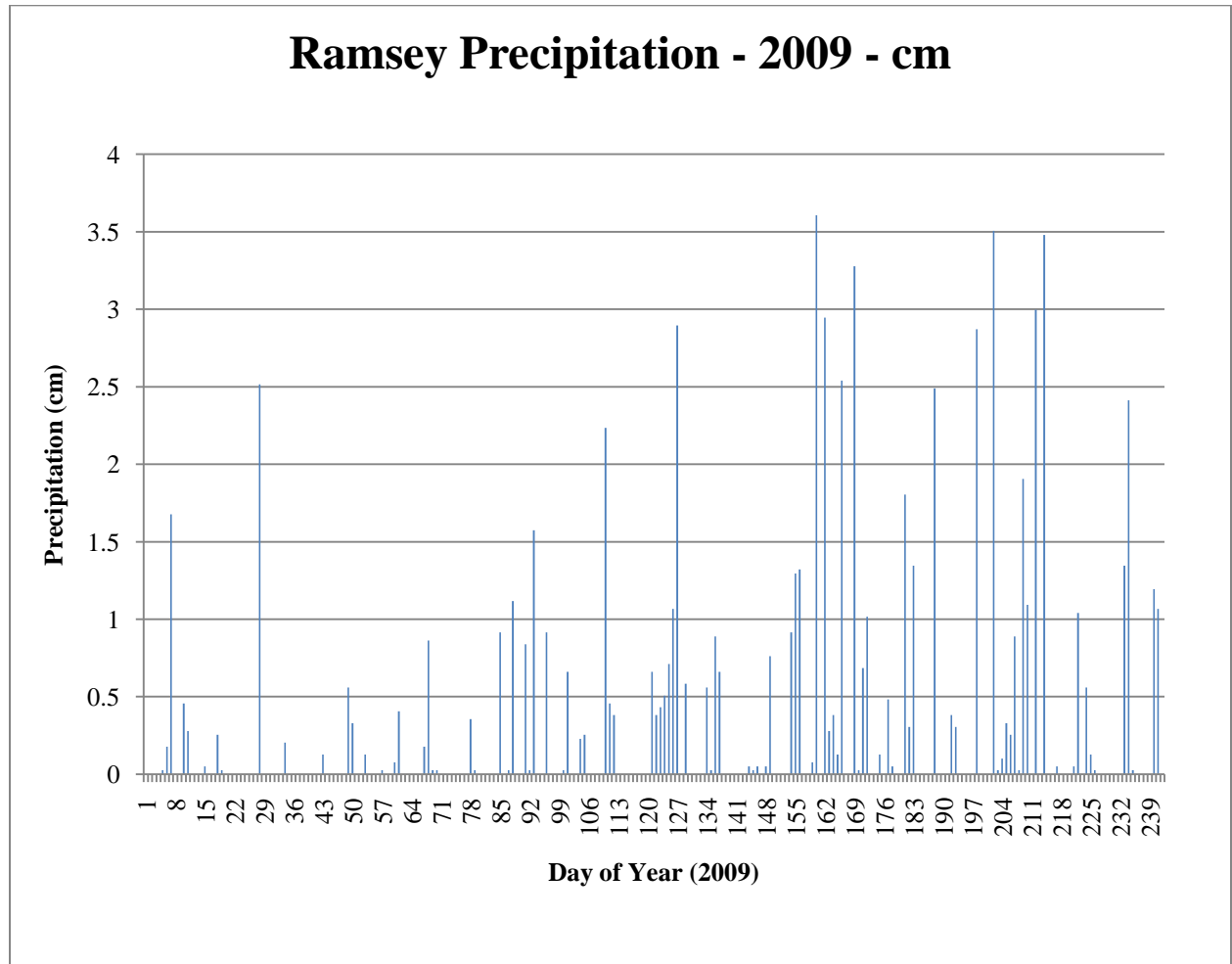


Figure A54: Precipitation record for Ramsey, New Jersey for period of project monitoring. Note that the Ramsey weather station is the closest station with a continuous, publicly-available, certified record of precipitation for the period of interest.

V. ECOLOGICAL INVESTIGATION OF BELCHER CREEK  
IN THE GREENWOOD LAKE WATERSHED

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