Forge Pond TMDL & Diagnostic/Feasibility Study

The first design project for CEE 577 is a TMDL and Diagnostic/Feasibility Study for Forge Pond in Granby, MA. Please work in groups of 3. You may choose your own partners for this assignment. I'll probably ask you to hand in the various sub-sections of the assignment as they are completed. These will be returned to you for inclusion in the final report.

Problem Statement

The quality of the water in Forge Pond has been deteriorating for many years. In the past few decades it has reached the point where the use of the pond is severely restricted.

1. Can no longer be used for contact recreation
    - heavy weed growth
    - duckweed covers parts like "green paint"
    - anoxic bottom
    - surface scums
    - massive seasonal algal blooms
2. Not likely to be used for recreational fishing
    - Only 4% gamefish (chain pickerel and largemouth bass)
    - most fish are white suckers and large golden shiners (rough fish)
    - high abundance of lesions and parasites
    - unbalanced size distribution.
3. Elevated organic concentrations and off-odors make it an undesirable water supply

You have been asked by the state and town to conduct a "TMDL and Diagnostic/Feasibility Study". This has as an objective to assess the total maximum daily loading, determine the source of the problems, to suggest possible remedial actions, and to comment on the feasibility of those actions.

Your assignment will include the following major tasks:

I. <u>Hydrologic Investigation</u>: Find drainage areas, and Estimate major inflows

II. <u>Water Quality Investigation & Model Development</u>: Determine WQ Parameters of importance, Identify & Evaluate Major Sources, and Estimate Loadings, present a calibrated model or some rational method to evaluate impacts of changes and management alternatives

III. <u>Propose Engineering/Management Solutions:</u> Discussion of options, impacts of various management strategies.

I. Hydrologic Investigation: Drainage areas, Major inflows, and Residence Time.

A. Determine Drainage Areas

1. Trace out the relevant drainage areas[1]

- Each group must acquire one hardcopy "Belchertown Quadrangle" U.S. Geological Survey topographic map (1:25,000 scale). You can download this from the USGS Store (http://store.usgs.gov)[2], and then print it full-size in color[3]. These can also be purchased for ~$9 from many camping stores (e.g., Gleason's in Northampton), and some office supply stores (e.g., Hastings, Staples)
- Trace out the drainage areas for the following tributaries: Bachelor Brook, and Weston Brook. These are called sub-basins. Also trace out the left-over drainage area that sits to the north of the dam, and to the east side of the pond, but doesn't fall into the Bachelor Brook sub-basin.
- Bring your map with the traced sub-basin boundaries into class on the date designated in the course schedule. I will check each for accuracy.

2. Measure the traced areas

- Determine each sub-basin area and estimate your uncertainty.
- Also determine the area of the Pond itself
- To save you from buying more topographic maps, I've given you the drainage areas for the other two sub-basins (Forge Pond Brook or Turkey Hill Brook, and the Unnamed Tributary)

B. Determine Major Inflows

1. Obtain rainfall data (1.11 m/yr based on 1988)

2. Calculate Inflows

- Use the "rational formula"
- Assume a runoff coefficient of 0.40

C. Calculate Mean Residence Time for the Pond

- Calculate pond volume; use the hypsographic profile of Forge Pond
- Determine mean water residence time

D. Prepare and Submit Draft Report on Hydrological Investigations

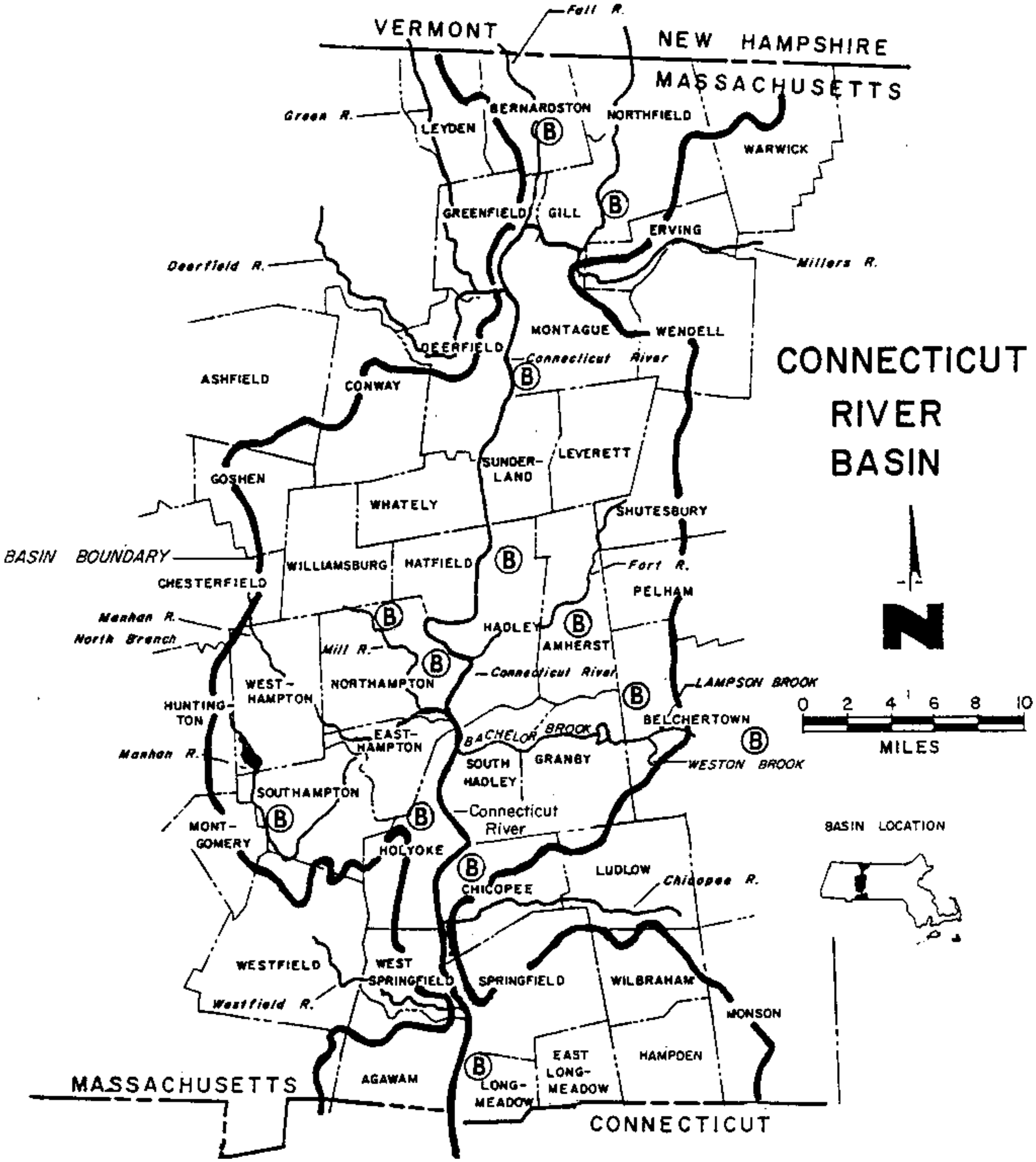
---

[1] What I have described here is an old methodology not using modern computer methods (e.g., GIS). If you are familiar with programs such as Arc-GIS, you are certainly free to use this approach instead. Alternatively, you might try using the web-based GIS interactive map on the USGS "StreamStats" web site.

[2] Select "Map Locator and Downloader", type "Belchertown" in the search box, hit "go", wait for the active map to appear with a drop pin near Belchertown, right click on this pin and select the 1990 Belchertown 5.5MB download

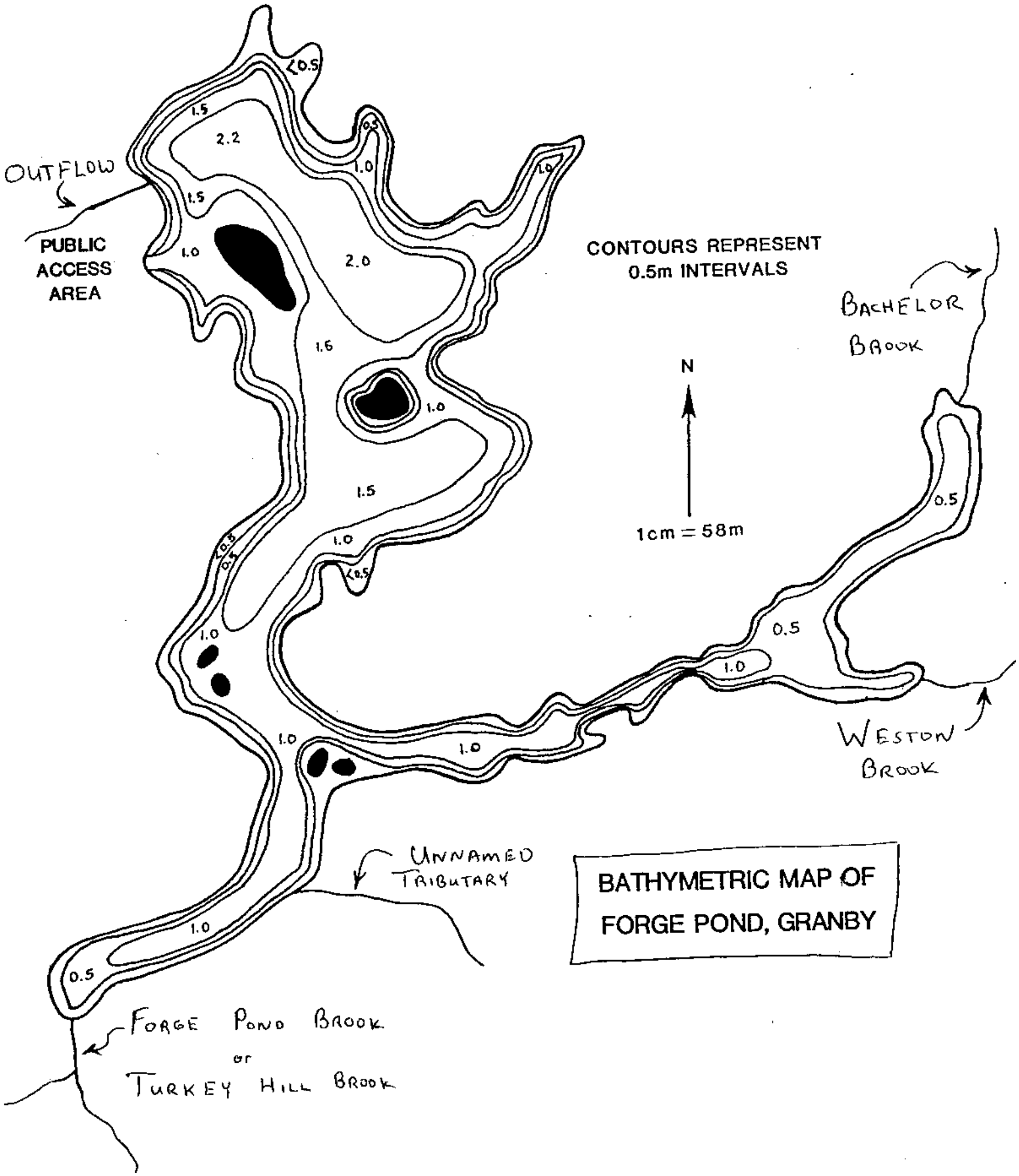
[3] The Perrell lab has a wide format printer that can be used for this: (HP DesignJet 1055CM; portrait orientation, ANSI E 34x44 in page size; settings: Coated Paper, Roll, 36 in roll)

Useful information for Part I.



Breakdown of Drainage Basins

Sub-basin	Drainage Area (square miles)
Forge Pond Brook	3.54
Unnamed Tributary	1.02
Bachelor Brook	????
Weston Brook	????



Hypsographic Profile of Forge Pond (original scale not preserved)

II. Water Quality Investigation & Model Development:

Determine WQ Parameters of importance, Identify & Evaluate Major Sources, and Estimate Loadings, present a model or some rational method to evaluate impacts of changes and management alternatives

Here you will want to formulate some sort of phosphorus model. This includes a model for the lake as well as a model for the watershed. The first choice is whether to use "mechanistic" and spatially resolved models or "empirical" and zero-dimensional models. The former may not be appropriate, as you really have no internal flow data on Forge Pond, nor do you have any system – specific data on phosphorus transformation and cycling. A classical mechanistic lake/river model formulation would incorporate explicit settling rates, release rates, hydrolysis rates, algal uptake rates, etc., none of which you have. While you do have spatially-resolved land use information on the watershed, your budget probably doesn't permit development of a fully mechanistic, distributed watershed model.

The level of information you have on the system (i.e., some water quality, but really no internal transformations), and the fact that this is a small lake with no internal flow information (forcing you to use a zero-dimensional model or CSTR) probably makes the empirical lake modeling approach the best choice. The size (budget) of the project and level of effort on the lake model probably makes an export coefficient watershed model most appropriate.

The objectives for your modeling work include two that focus on the lake itself (1&2) and two that are more concerned with the watershed (3&4):

1. To test the response of Forge Pond to its known phosphorus loadings, verifying that it does behave like most lakes of its size, and thereby giving confidence that all major loads have been accounted for, and that there are no other important processes that have been ignored.
2. To refine the lake model, better adapting it to Forge Pond, so that impacts of future scenarios can be better predicted.
3. To test the expected watershed export of phosphorus against the known export, so that you can verify that you've considered the major sources of phosphorus in the watershed.
4. To refine the export model, better adapting it to the Forge Pond watershed, so that the impacts of future scenarios can be better predicted.

Recommended sequence of tasks

A. Calculate loadings to FP based on estimated flows and measured concentrations
B. Use Vollenweider's 1975 model[4], as summarized by Reckhow & Chapra (1983), and presented in the class handout, "Empirical Lake Model for Phosphorus with Uncertainty" along with loadings from part "a" to calculate in-lake phosphorus concentration (no need at this point to use the export-coefficient areal loading method). You may also want to consult the material presented in class on this (Lecture #8).
C. Compare the predicted phosphorus value with the actual measured one. Comment, especially as regards to comparison with other lakes. Make adjustments to Vollenweider's model if needed. When considering this, you might also want to look at the outflow phosphorus level make appropriate comparisons with the total loading.

[4] Vollenweider, R.A., 1975, "Input-Output Models with Special Reference to the Phosphorus Loading Concept in Limnology," Schweiz. Z. Hydrol. 37: 53-84.

D. Next consider the watershed model. I would use an export coefficient approach. As a first approximation, you have export coefficients in the Lake Higgins example. For more depth, you should consult the Reckhow et al., 1980 compilation[5]. Compare predictions based on these coefficients with the loadings you calculated from actual concentrations.
E. Adjust or re-select your export coefficients to better match observations.
F. Present your final system model including calibrated models for the watershed and pond

Important Data for Part II

Land Use in the Forge Pond Watershed (estimate from 1989)

Land Use	% of Total
Forest	75.4
Agriculture	8.9
Urban/Residential	7.2
Marsh/Wetland	2.4
Institutional	2.1
Open	1.8
Abandoned Fields	0.8
Lakes (w/o Forge Pond)	0.8
Commercial	0.6

Notes:

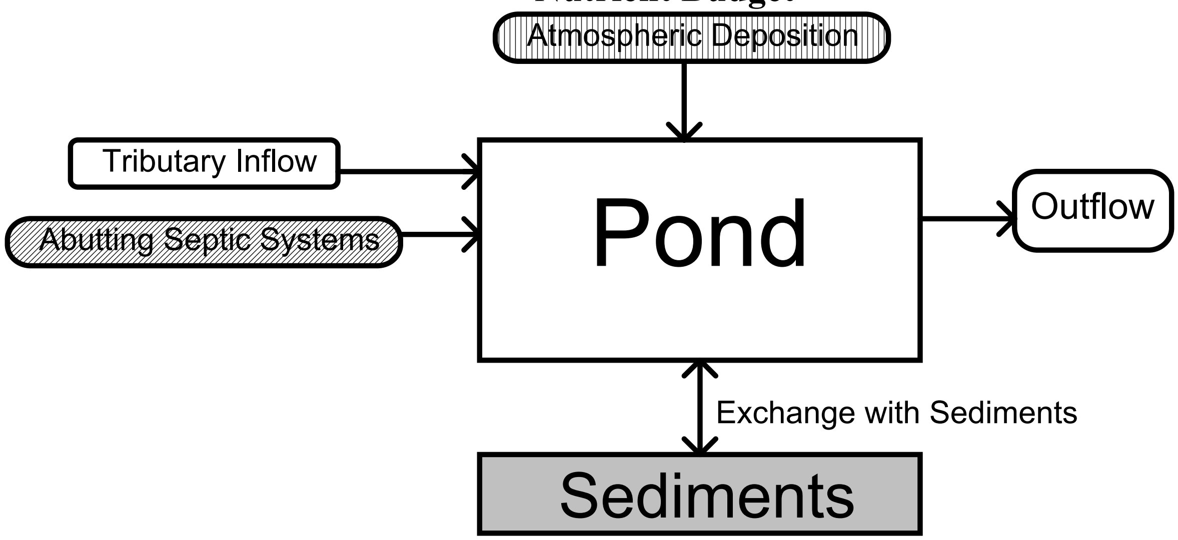
Institutional: St. Hyacinth's Seminary, Belchertown State School
Open: power transmission lines, road corridors, sand and gravel pits, town landfills, and automobile junkyards
Abandoned Fields: mostly agricultural lands undergoing secondary succession
Commercial: primarily Belchertown center

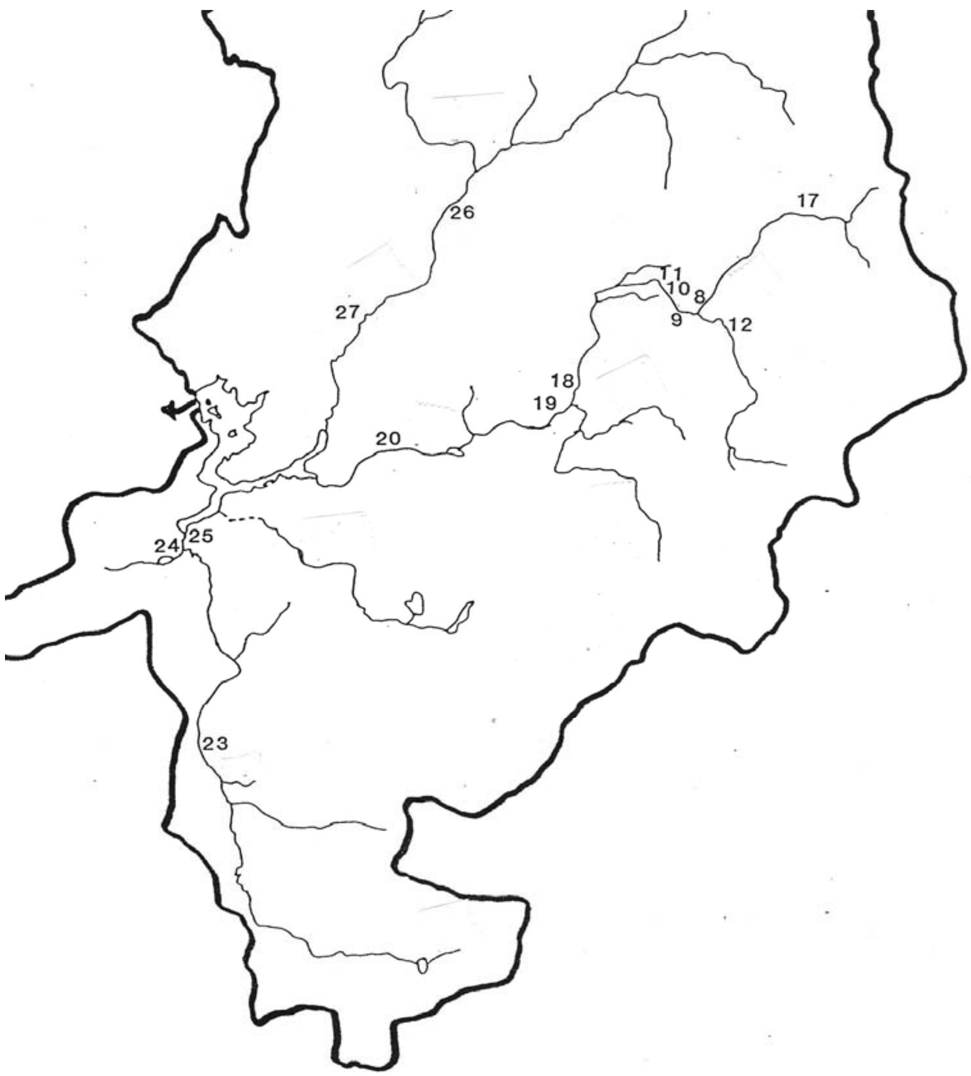
[5] Reckhow, KH, MN Beaulac, JT Simpson, 1980, Modeling Phosphorus Loading and Lake Response under Uncertainty: A Manual and Compilation of Export Coefficients. USEPA 440/5-80-011.

Major Database (Regular Sites) on Water Quality in Forge Pond and Major Inputs/Outputs (Jan-Dec, 1986)

Parameter	Bachelor Br.		Weston Br.		Forge Pond Br		Unnamed Trib		Forge Pond				Outlet		Units
	@ entry to FP		@ entry to FP		@ entry to FP		@ entry to FP		Surface		Bottom		@ outlet from FP		
	Mean	Min Max	Mean	Min Max	Mean	Min Max	Mean	Min Max	Mean	Min Max	Mean	Min Max	Mean	Min Max	
Total-P	15	10 50	210	92 400	31	10 56	23	10 50	77	23 180	98	29 250	79	30 160	µg/L
Ortho-P	11	10 44	188	17 400	12	10 38	15	10 40	35	10 70	45	10 130	34	10 90	µg/L
NH_4-N	0.066	0.01 1.3	0.109	0.01 0.41	0.099	0.01 0.64	0.063	0.1 0.12	0.04	0.01 0.16	0.05	0.01 015	0.059	0.01 0.17	mg/L
NO_3-N	0.297	0.06 0.89	0.351	0.01 1.2	0.063	0.02 0.18	0.137	0.02 0.31	0.09	0.01 0.39	0.09	0.02 0.39	0.157	0.01 0.76	mg/L
TKN	0.448	0.18 3.5	0.672	0.37 0.84	0.407	0.10 0.80	0.265	0.11 0.61	0.77	0.14 2.31	0.82	0.13 2.2	0.557	0.21 2.3	mg/L
Diss O_2	10.7	6.6 13.6	10.7	6.8 13.6	7.2	0.2 12.4	8.3	5.9 11.6	11.0	6.3 16.1	4.9	0.2 11.8	10.3	5.5 14.0	mg/L
Conduct.	130	84 320	193	139 335	99	58 235	81	54 97	131	89 230	131	94 240	132	87 240	µmho/cm
Chloride	11	6 24	26	5 40	6	2 13	7	2 10	13	7 18	14	8 26	14	7 25	mg/L
Chloro-phyll a									49.8	1.8 231.8					µg/L

Nutrient Budget





Location of Supplemental Sampling sites

Supplemental sampling Data for Total Phosphate (μg/L): Single samples: May-Aug 1987.

Site	5/19/87	6/18/87	8/27/87	Description
8	50			Lampson Brook, north branch, 1500 ft downstream of #7
9	80	140	30	Lampson Brook above Belchertown WWTP outfall
10	2,440	2,250	4,060	Lampson Brook, at Belchertown WWTP outfall
11	1,340		2,110	Lampson Brook below Belchertown WWTP outfall
12		100		Lampson Brook, south branch upstream of Belchertown WWTP
17	100			Lampson Brook, upper northern branch @ Hannum Road
18	650	1,340	1,210	Lampson Brook, 100 ft above confluence with Weston Brook
19	460	1,220	1,040	Weston Brook, 50 ft downstream of confluence with Lamson Br.
20	400	910	790	Weston Brook, at Rural Street (same as regular site)
23	150			Forge Pond Brook below Chicopee St.
24	190			Tributary to Forge Pond Brook
25	50			Forge Pond Brook at route 202
26	60			Bachelor Brook at Stebbins Road
27	10			Bachelor Brook 500 ft downstream of #1

Estimating Pollutant/Nutrient Loadings

Tributary Inflow results in nutrient loading that can be easily calculated from flow and concentration.

$$W=QC$$

Atmospheric Deposition occurs when phosphorus falls directly on the surface of the lake. This phosphorus may be come from the settling of dust particles or from rain or other forms of moisture. The amount that falls in a year is directly proportional to the surface area of the lake.

Atmospheric deposition factor for phosphorus may be estimated using:

0.45 kg-P/ha/yr

Abutting Septic Systems contribute nutrients, because they typically only remove 75% of phosphorus that is generated in the home. The remaining 25% will reach an abutting surface water (e.g., a lake) or groundwater, if there is no nearby surface water. This loading can be obtained by a "per capita generation rate" multiplied by the number of abutting dwellings, the occupancy rate (number of persons per dwelling), the average occupancy span (fraction of the year each person is living there), and the fraction remaining after passing through the septic system.

Per capita waste generation rate for phosphorus:

1.8 kg/person/yr

Note:

ha = hectares = 10,000 square meters
kg = kilogram

Wastewater Treatment and Disposal in the Forge Pond Watershed

Individual, On-site Systems

Abutters are of greatest importance, others are probably inconsequential

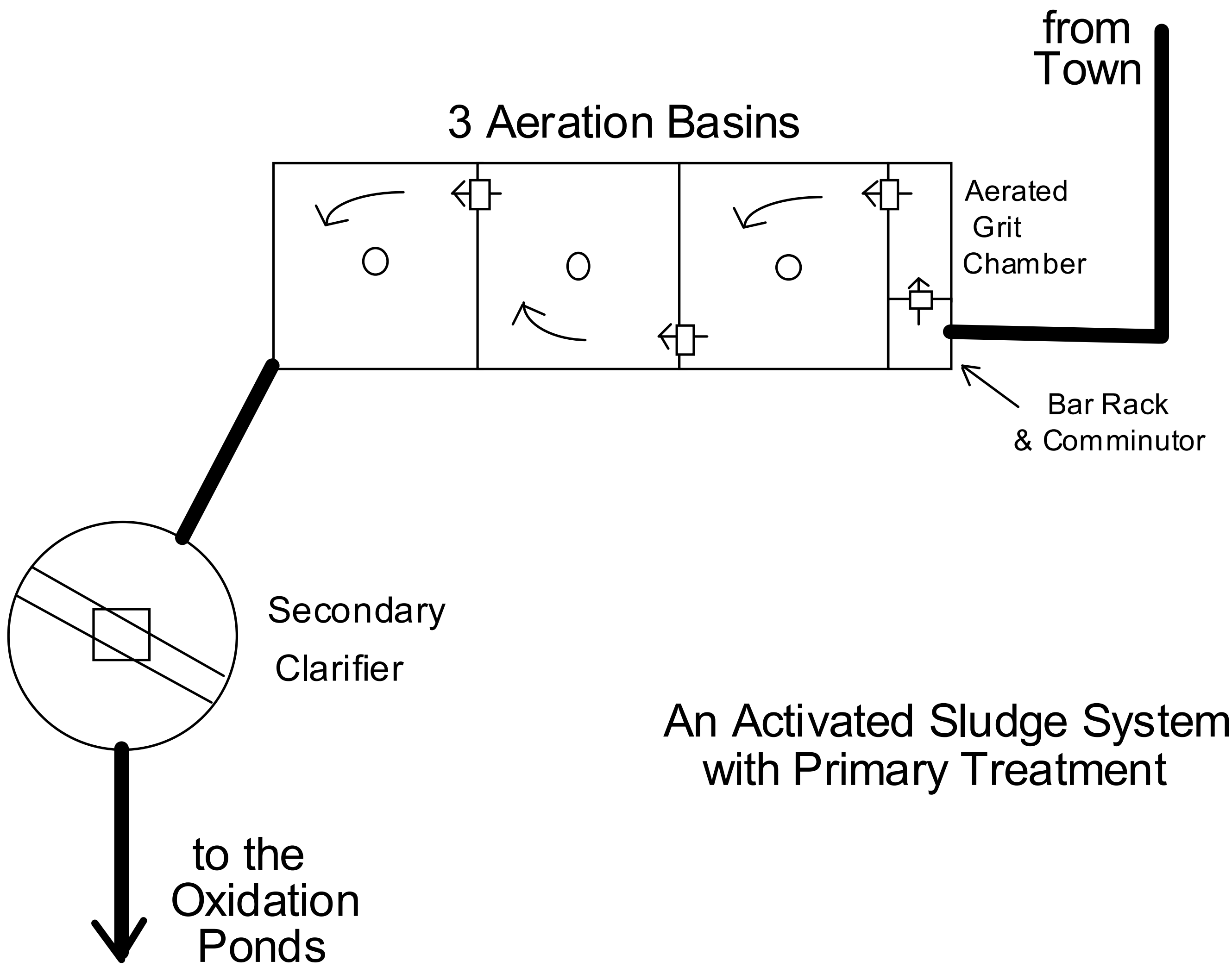
at Forge Pond, there are

- 24 homes located on the shore.
- an average of 2.3 persons per home
- each person lives his/her home an average of 93% of the year.

Community Treatment Systems

In assessing the current impact of the WWTP discharge to Lampson Brook, you will need to consider the population in Belchertown and the fact that only a portion of the total population is sewered (~20%), the rest being on individual septic systems. The Donahue Institute provides some good population data and projections on their website at: http://www.massbenchmarks.org/statedata/data.htm

In 1989, the plant had a comminutor, aerated grit chamber, a series of aeration tanks, trickling filter and secondary clarifier. All water was then passed through a series of lagoons, totaling 80,000 cubic feet in volume. Sludge from these lagoons has been removed periodically and placed in a landfill. Effluent was seasonally chlorinated and discharged to Lampson Brook. The Belchertown WWTP was not designed for nutrient removal. Average flow in 1985 was about 0.35 MGD, whereas it had risen to about 0.50 MGD by 2007. The Belchertown WWTP has been upgraded since the late 1980s when the water quality data you have in this handout were collected. For this reason, you will want to use point source concentrations from the WWTP that are appropriate to the plant prior to the upgrade (i.e., the plant described below).



Front End of the Belchertown WWTP (ca. 1989)

III. Propose Engineering/Management Solutions

For estimating impacts of management alternatives, you should consider using the model developed in part II as much as you can. There will be some options that may lend themselves to this type of analysis (e.g., reduction of point sources, changes in land use) and some that will not (e.g., biomanipulation). You may also want to consider impacts of population growth (i.e., since 1989 when water quality data were collected, and into the future), as well as anticipated climate change.

Important information for assessment of Management Alternatives:

Watershed Management vs In-Lake Management

Watershed/Lake Area Ratio	**Management Approach**
<10	In-lake measures may work by themselves.
10-50	In-lake measures are difficult, but may still work. Watershed management may be needed.
>50	In-lake measures are infeasible, watershed management is needed.

In-Lake Management Techniques

	Technique	**Notes**
1	Dredging	removal of sediments
2	Macrophyte Harvesting	mechanical removal of plants
3	Biocidal Chemical Treatment	chemicals added to inhibit growth of undesirable plants
4	Water Level Control	flooding or drying of troublesome areas to control growths
5	Hypolimnetic Aeration or Destratification	addition of oxygen, and mixing
6	Hypolimnetic Withdrawal	removal of bottom waters low in oxygen and high in nutrients
7	Bottom Sealing/Sediment Treatment	obstruction of the bottom by physical or chemical means
8	Nutrient Inactivation	chemical precipitation or complexation of dissolved phosphorus, nitrogen, etc.
9	Dilution and Flushing	increase flow to help "flush out" pollutants
10	Biomanipulation or Habitat Management	encouragement of biological interactions to alter ecosystem processes

Watershed Management Techniques

	Technique	Notes
1	Zoning/Land Use Planning	Management of land use
2	Stormwater/Wastewater Diversion	re-routing of wastewater flows
3	Detention Basin Use and Maintenance	increase time of travel for polluted waters so that natural purification processes act
4	Sanitary Sewers	installation of community-level collection systems
5	Maintenance and Upgrade of On-site Treatment Systems	better operation & performance of home septic systems, etc.
6	Agricultural Best Management Practices	use of improved techniques in forestry, animal and crop science
7	Bank and slope stabilization	erosion control to reduce sediment and associated loadings
8	Increased street sweeping	frequent washing and removal of urban runoff contaminants
9	Behavioral Modifications	
	a. use of Non-phosphate detergents	eliminates source of P
	b. eliminate garbage grinders	reduces general organic loading
	c. minimize lawn fertilization	reduces nutrient loading
	d. restrict motorboat activity	reduce turbulence and sediment resuspension
	e. eliminate illegal dumping	reduce a wide range of conventional and toxic inputs

Guidelines for the Preparation of your Report entitled: Diagnostic/Feasibility Study of Forge Pond

You should prepare your report in the style of a classic engineering technical report. This should include:

1. **Title Page**
    - title
    - name of authors
    - authors' affiliation
2. **Abstract**
    - about 200 words in length
    - summary of recommendations
    - brief mention of critical results, logic behind recommendations, how results were obtained
3. **Main Body**
    - highly variable in length
    - full recommendations
    - full discussion of supporting arguments
    - summary presentation of data used
    - discussion on how data were collected and analyzed
4. **Appendices**
    - broken down into sections (hydrologic, water quality modeling, management, etc.) and perhaps subsections
    - listing of important data
    - full description of how data were analyzed including uncertainty
    - detailed descriptions of field methods or laboratory methods used
    - justification for selection of model parameters

As a first step I ask you to submit for inspection a draft report on the Hydrological Investigations. The information you gathered during this phase of the project would go into one or more Appendices (e.g., Appendix A: Determination of Sub-basin Drainage Areas.). Your analysis of the Forge Pond water budget or mass balance, which is based on this information, would make up one section of the Main Body. Please remember to prepare only one report per group.

Later you need to incorporate your Water Quality Investigation (including phosphorus budget/loading) data and discussion in the appropriate sections of the report. And as a final step, recommendations or proposed engineering solutions must be presented. The Main Body should begin with these, as this is your "bottom line". A reasonable length for the Main Body is 4-10 pages. The Appendices may be substantially longer.

For individual reports on land use in the towns of Belchertown and Granby, refer to the Interim Water Quality Management Plan for the Lower Pioneer Valley, prepared by the Lower Pioneer Valley Regional Planning Commission, Sept., 1979.

Portions of this document that pertain to Belchertown and Granby have been reproduced in the report, "Water Quality Management Plans for the Towns of Belchertown and Granby, MA"

You may find some additional resources that have been published more recently than 1979. Please feel free to cite and use these.