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Based on the water quality evaluation described in earlier sections, ten major problem areas were identified in the Pennichuck Watershed as summarized on Table 9-1. Each of these problems is described in more detail below, followed by recommended actions to alleviate the problem or to minimize the problem in the future.

9.1 Findings

Problem 1: Loss of Baseflow/Increased Runoff/Stream Channel Modifications

As urbanization encroaches in all parts of the watershed, stormwater runoff is increased. Because the stormwater picks up many pollutants as it passes over impervious surfaces, a higher proportion of stormwater flow in the watershed is not beneficial to water quality. At the same time that stormwater flows increase, infiltration and recharge of groundwater decrease. Although it may take a long time to affect regional groundwater levels, it is likely to be the eventual result. As groundwater levels decrease, groundwater discharge to streams during low flow conditions also decreases. This has already been seen in the Pennichuck watershed.

Baseflow provides a typically very clean source of water to ponds and streams, so its loss is detrimental to the health of the watershed. Fish and wildlife, wetlands, and water supply resources are all affected by this problem. The decline of water quality and quantity for water supply are particularly important.

The most easily measured factor in evaluating the extent of the problem is the measurement of total imperviousness or the percentage of area that is not "green" (Schueler, Fall 1994). Schueler defines imperviousness as the sum of roads, parking lots, sidewalks, rooftops and other impermeable surfaces of the urban landscape. There are two primary components of imperviousness: 1) rooftops; and 2) transportation system. The rooftop component is somewhat fixed, while the transportation component is highly varied based on the layout of streets and parking.

Table 9-1 Top 10 Problems in Pennichuck Watershed
1. Loss of baseflow, increased stormwater runoff and stream channel erosion result in declining water quality.
2. Future development is likely to increase these problems.
3. The Pennichuck ponds appear to be filling in rapidly, which will further exacerbate water quality and quantity problems.
4. Transportation facilities in the watershed are widespread and have major impacts on water quality.
5. Agricultural activities that result in livestock using tributary streams for watering may result in the introduction of waterborne pathogens and high nutrient loads.
6. Multiple "hot spots" in the watershed pose chemical risks to the water supply and may threaten biological activity that normally cleanses water quality.
7. There is a general lack of understanding of watershed protection principles among the regulatory, planning, public works and engineering communities.
8. There is a general lack of understanding of watershed protection principles among the watershed businesses and residents.
9. Pennichuck Water Works Corporation lacks up to date regulatory authority within the water supply.
10. The available database is lacking.

As imperviousness increases, stream channels respond to the more severe and more frequent flooding by increasing their cross-sectional area to accommodate the higher flows. A loss

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of stable streamside vegetation may result. This results in channel instability, which tends to trigger a cycle of stream bank erosion and loss of stable aquatic habitat. This loss of stability may increase both the rate of filling in of ponds on the system, and water quality in terms of turbidity and the pollutants that are carried with the increased sediment load.

Table 9-2. Pennichuck Watershed Imperviousness		
Subwatershed	Imperviousness	Subwatershed Drainage Area (in acres)
PBS	14%	1,285
PBB	29%	2,390
PBH	15%	1,508
PBP	5%	1,978
WBE	23%	1,365
WBS	5%	3,193
WBN	19%	1,425
SPB	17%	1,516
BFB	36%	1,006
MB1	6%	2,317
Total Acreage		17,983

Total Imperviousness =2728/17983=0.152=15.2%

The increasing imperviousness can also increase phosphorus loads, and result in overenrichment of the receiving waters, in this case the Pennichuck ponds.

Impervious surfaces also increase local air and ground temperatures by as much as 10-12° (Schueler, 1994). This is the result of the impervious surfaces absorption and reflection of heat. Stream temperatures may ultimately be affected with increased stormwater and decreased cool baseflow discharges. The stream warming is detrimental to both aquatic life and water supplies, resulting in the loss of aquatic fish and other species as well as potential increases in nuisance species and aquatic vegetation.

Imperviousness also increases annual water level fluctuations in fresh water wetlands. Studies by Taylor, 1993, showed that the richness of both wetland plant and amphibian community dropped sharply as stream watersheds increased in imperviousness. As stream habitat becomes more degraded, both aquatic vegetation and animals are negatively affected. Diversity tends to be reduced, with native species being replaced by invasive plants. Most aquatic life, other than the nuisance invasive aquatic weed species and nuisance species of invertebrates such as blood worms (pollution-tolerant *Chironomidae*) are the survivors. This change is detrimental to both recreational users of the watershed and to the water supply.

Table 9-2 shows the percent imperviousness by subwatershed of the Pennichuck watershed. Total watershed imperviousness is estimated at 15%. Schueler (1994) suggests that the cycle of stream and water quality degradation begins at approximately 10% imperviousness. He also suggests that once background loads exceed 20-25%, it may be difficult or impossible to fully restore water quality.

Problem 2: Impacts of Future Development on Water Quality Expected

Not only has water quality deteriorated over time, but it is likely that it will deteriorate further as future development and urbanization of the watershed occurs. The buildout analysis described in Section 7.0

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suggests that nutrient loads will increase significantly. This increase in nutrient loading will result in more pronounced taste and odor problems during the summer when algal blooms are common, higher turbidity during parts of the year, and increased stream channel erosion. Fish kills are likely, along with increases in the frequency and intensity of storm flows. Base flow may be further decreased, and eventually may result in the primary stream drying up during droughts. This could have a serious effect on aquatic habitat and wetlands in the watershed, further decreasing their ability to filter pollutants during storm flows.

As time goes on, if imperviousness increases to the extent that it is physically possible, Pennichuck will likely have to rely more on other sources of supply and decrease its use of the Pennichuck ponds. Since this is likely to occur at the maximum demand time of dry summertime, it could eventually result in difficulties in meeting maximum day demands for the system. If adequate water is available for use, it may require additional treatment. Chemical use for settling and filtration expenses are also likely to increase as water quality deteriorates.

Since EPA is expected to increase the requirements for systems with poor quality sources, Pennichuck may be subject to these additional treatment requirements as water quality deteriorates. EPA is likely to require that this additional treatment is at the front of the treatment train, for example, pre-sedimentation facilities. This provides very strong economic incentive to improve the raw water quality of the Pennichuck pond system.

Problem 3: Chain Ponds are Filling In

Limited sampling conducted for this study suggests that the chain ponds are quickly filling in with sediment from the watershed. In some cases, the ponds may already be largely filled with loose sediment, and washing over sediment during large storm flows. Should this happen, water quality could deteriorate much more rapidly than it has in the past. This is because the chain pond system has acted as a presedimentation system for the water supply.

As turbid, polluted storm flows enter the chain pond system, they are retained in the ponds, providing a trapping effect for many pollutants.

As turbid, polluted storm flows enter the system, they are retained in the ponds, providing a trapping effect for many pollutants. Most of the significant pollutants, including phosphorus and many bacteria, are "particulate" or tend to be associated with particles of soil. Thus they are transported most effectively with soil particles. These same particles tend to settle out in slow areas and in ponds, and if the ponds are deep enough, the sediments are retained.

In natural systems, sediments slowly build up over millions of years until ponds eventually become wetlands and finally land. In a natural system without urban development, this could take millions of years. In the Pennichuck watershed, this same filling in process could occur in a matter of decades or even years as urbanization and its resultant

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imperviousness increases uncontrolled.

Even if the sediments are not spilling over, they may be exerting a water quality impact through their oxygen demand. As ponds develop a large sediment layer, the decomposition of this material typically creates an oxygen demand. As the sediments decompose and degrade, oxygen is pulled out of the water, often creating an oxygen deficient layer at the bottom of ponds and lakes. As oxygen is lost from this lower layer, chemical changes begin to occur that result in the release of some of the trapped pollutants from the sediments back into the water column. This can occur to the extent that some ponds actually produce a phosphorus load internally, hastening the eutrophication process exponentially. This can result in water quality that is actually worse than the level of watershed development would suggest.

Roadway drainage may result in the direct transport of hazardous pollutants to the water supply.

Problem 4: Transportation Impacts

Because the Pennichuck watershed has developed at a rapid pace and because it contains many large and small roadways, transportation impacts are particularly problematic. Cars, so critical to life in Southern New Hampshire, are a major source of a number of types of watershed pollutants. This includes copper from brake pad wear, zinc from wear and tear of automobile tires, atmospheric deposition of lead from the exhaust of diesel-fueled vehicles, solvents, oils and other automotive fluids from automotive leakage and repairs, and other pollutants from exhaust. The result of all this is that roadways are loaded with pollutants which wash into nearby watercourses during every rainstorm.

Although some advances have been made in controlling this pollutant load in newer roads, controls on major roadways are typically inadequate even now, and particularly on older roadways where the typical goal was to get the water to the nearest stream as quickly as possible through piping. This rapid transport increases pollutant loads and exacerbates the problem of imperviousness and increased stormwater runoff. Additionally, roadways, airports, and parking lots provide mostly uncontained areas for spills of hazardous materials and other undesirable fluids. These may result from accidents, since the typical response to these accidents is to wash spills off the road and into the nearest waterway. Because roadway drainage is typically uncontrolled in the watershed, this may result in the direct transport of hazardous pollutants to the water supply.

Aquatic habitat in the watershed is also likely to be damaged, with kills of many of the organisms that normally act to remove pollutants from the water column. Since a diversity of organisms helps to control water quality impacts by decomposition, the loss of these organisms is a detriment to both water supply and recreational uses of the watershed such as fishing and aesthetic enjoyment.

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Problem 5: Agricultural Impacts

In some limited parts of the upper watershed, particularly in Hollis, there remain large tracts of agricultural lands. These lands generally provide a benefit to water quality in the watershed by retaining pervious surfaces. However, where cattle and horses are pastured with use of tributary streams for their drinking water source, they may present a hazard related to pathogenic organisms. A number of pathogenic organisms are produced by humans and animals, and if feces enter streams untreated, the pathogens must be removed before the water can be distributed. Unfortunately, some of the most recently discovered organisms, particularly *Cryptosporidium*, have escaped conventional treatment systems and disinfection to cause waterborne disease outbreaks. Since this particular organism is often associated with cattle, particularly calves, there is the potential for significant water quality impacts.

This organism, which sickened 400,000 people in Milwaukee and killed 100, is commonly found in large numbers in poor quality sources of water. It is highly resistant to disinfection, and has escaped conventional treatment systems when they have become overloaded due to the large number of organisms and operational practice such as recycled backwash. Even with every precaution taken at the treatment end, it is still critical to limit the number of these organisms entering raw water sources.

Problem 6: Hot Spots

As described in Section 6.0, on pollution sources, the watershed contains a number of point sources or hot spots. These include known hazardous waste sites, permitted hazardous waste generators where spills of significant hazardous chemicals could occur, and smaller potential sources of pollutants such as car dealerships, gas stations, and auto repair shops. From these locations, a variety of hazardous chemicals, oils, and nutrient loads from car washing activities may emanate. These areas may be a significant source of pollution if not adequately controlled with Best Management Practices. There are dozens of each of these locations within the watershed, particularly the most urbanized portion of the watershed along Route 101A.

Problem 7: Lack of Community Understanding

The problems identified above are well known to watershed engineers and scientists, however, they are not typically recognized as issues by most regulatory, planning, public works staff or the engineering community in general. This is largely because many of the concepts are relatively new (within the last ten years) but are increasingly being applied around the United States. In general there has been resistance to change among the engineering community, largely

Many fishermen lament the loss of favorite trout streams - now gone because trout can not tolerate the higher stream temperatures and pollutant loads.

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because standardization of the methods has not yet been done. This has also resulted in a reluctance by some planning boards and regulatory authorities to address these problems, in part because many of the solutions are relatively new. In many cases, regulatory, planning, and engineering communities are just not aware of the issues yet.

Problem 8: Lack of Understanding Among General Public

Many federal and state "watershed initiatives" developed so far by EPA and DES have focused on the larger watersheds of rivers such as the Merrimack. While these initiatives are beginning to get the word out, most residents in watershed towns and in general are probably not familiar with many of the concepts discussed in this report. However, it is likely that they are familiar with the degradation of the water resources around them. For example, many fishermen often lament the loss of their favorite trout fishing streams. This is usually due to the fact that trout can not survive in the higher temperatures that result from increased stormwater flows off heated impervious areas and the loss of shaded stream channels that results from eroded stream banks. Many people have also become aware of drinking water quality problems based on press accounts of waterborne disease outbreaks such as the one that occurred in Milwaukee.

Most people in the watershed are probably not aware of the fact that their everyday actions can have a significant impact on the environment and water quality.

Still, most people in the watershed are probably not aware of the fact that their everyday actions and their own property have a significant impact on water quality. Similarly, they are probably also unaware of the things that they can do as individuals to reduce the impacts.

This information is also not taught in the schools. For the most part, teachers are unaware of the problems, and this subject is not included in most curriculums. Science teachers may touch on the subject, but a focused program as related to the Pennichuck watershed is not known to be taught.

Problem 9: Lack of Regulatory Control/Authority

Pennichuck Water Works Corporation does not have any authority within the watershed. There is certainly influence based on the fact that many of the Towns are supplied water by Pennichuck, but in some cases there is little incentive for Towns to cooperate other than the fact that neighbors helping neighbors is the right thing to do. Watershed regulations do exist, authorized by the State Legislature in 1934. However, these regulations are outdated and do not provide the kind of controls that would assist Pennichuck Water Works Corporation in reducing water quality impacts within the watershed. Without more specific regulations, Pennichuck must rely on the goodwill of watershed communities in protecting its water supply. While most communities have been generally cooperative in the past, it is unknown how they will

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react when asked to address the impacts from their communities.

Problem 10: Water Quality Database is Insufficient

While limited sampling was done for this study, and previous analysis information was incorporated into the report where possible, a solid database of raw water quality information within the watershed does not exist. This is not uncommon, since most water systems have relied on finished water quality and many water systems still rarely collect watershed information or data. However, this results in a lack of understanding of specific problem areas that could be corrected, and a lack of statistical significance in database trends. Other things, such as sediment depths in the ponds, are unknown. Stormwater quality, which is a serious threat to water quality, has not been compared between subwatersheds or sights. Stream channel impacts in different portions of the watershed due to urbanization is also unknown. This lack of a database makes comparison to water quality goals in the future difficult.

9.2 Recommended Actions

Based on the top ten problems identified above, recommended actions have been developed to address each problem. For ease of understanding, these are divided into three categories: 1) prevention; 2) remedial measures; and 3) monitoring.

Table 9-3 Methods to Reduce Future Imperviousness of the Pennichuck Watershed

Require that post-development runoff equals predevelopment runoff	Subdivisions and commercial/industrial developments should be required to match post-development conditions to pre-development conditions for runoff up to the ten-year storm. All water from a two-year storm should be infiltrated. Peaks should be attenuated and stored for slow release in larger than ten-year storms (up to 100-year).
Minimization of Parking Lot Impacts	• Use angled parking and smaller spaces on one-way streets and parking lots • Reduce parking ratios required where possible • Use vertical parking structures in urban areas where possible • Use permeable spillover parking where appropriate • Modify landscaping of parking lots to use permeable dividers and street side buffer strips (See Figure 9-1)
Reduce Transportation Impacts of Subdivisions	• Encourage cluster development wherever possible • Use skinny streets to reduce roadway impacts • Use grass swales instead of curbs and gutters • Use one-sided sidewalks or paths • Reduce cul-de-sac radii or use central cul-de-sac permeable doughnuts (Figure 9-2)
Use Onsite Infiltration Wherever Possible	• Roof leaders and sump pumps should be recharged onsite instead of conducted to the storm drain or sewage system • Leave native vegetation between residential lots for privacy and recharge • Leave stream buffers between residential developments and streams • When rezoning, use lowest density residential zoning possible
Clearing/Grading Plans	• Develop clearing and grading construction guidelines that minimize site disturbance and vegetation loss • Require grading and erosion control plans, and inspect same during progress of construction
Landscaping	• Encourage the use of native species for landscaping wherever possible • Leave native vegetation in place as a buffer • Use mulched areas for part of lawn • Minimize lawn size and increase native landscaped area
Other Onsite Recharge Methods	• Connect roof leaders and sump pumps to recharge gravel • Recharge all onsite runoff wherever possible
Source: Adapted from Schueler, Fall 1994, Watershed Protection Techniques, V1, N3. "The Importance of Imperviousness"	

Prevention Measures

Prevention Method 1: Reduce future imperviousness

As discussed in findings above, the Pennichuck watershed is currently at a hefty 15% imperviousness overall. This is in spite of the fact that some portions of the watershed, largely in

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Hollis, are mostly undeveloped. Some subwatersheds, as was shown on Table 9-2, have extremely high imperviousness levels (up to 36%). The related water quality that is produced from these impervious subwatersheds is poor.

Table 9-4. Buffer Zone Requirements	
Planning Stage	1. Require buffer limits on all clearing/grading and erosion control plans. 2. Record all buffer boundaries on official maps. 3. Clearly establish acceptable and unacceptable uses 4. Establish clear vegetation targets and rules for different zones of the buffer. 5. Provide incentives for owners to protect buffers through perpetual conservation easements rather than deed restrictions. 6. Use level spreaders or other techniques as needed to prevent channelized flow through the buffer.
Construction Stage	1. Pre-construction stakeout of buffers to define the limits of disturbance. 2. Set limits of disturbance based on drip-line of the forested buffer. 3. Conduct pre-construction meeting to familiarize contractors and supervisors with limits of disturbance. 4. Mark limits of disturbance with a silt fence barrier, signs or other methods to exclude construction equipment. 5. Inspect the buffer during construction to assure that channelization is not occurring through the buffer.
Post-Development Stage	1. Mark buffer boundaries with permanent signs or fences describing allowable uses. 2. Educate property owners or homeowner associations on the purpose, limits and allowable uses of the buffer. 3. Conduct periodic walkthroughs to inspect the condition of the buffer network. 4. Reforest grass or lawn buffers.
Source: Adapted from Schueler, Technical Note 7, Watershed Protection Techniques, V1N1, Feb. 1994.	

To reduce future imperviousness, prevention measures are needed. Pennichuck Water Works Corporation currently tries to work with Planning Boards and Conservation Commissions in the watershed Towns to encourage Best Management Practices. However, a more concerted effort needs to be made in this area. Table 9-3 outlines some of the most important actions that can be taken by watershed Planning Boards and Conservation Commissions to reduce imperviousness.

The most important method to reduce imperviousness is to require developers to control runoff from new subdivisions and to incorporate remedial stormwater measures into existing facilities when they come up for substantial modification.

This can be done (and has been elsewhere) by requiring that post-development conditions not exceed pre-development conditions for stormwater. During very large storms (greater than ten-year storms) this is sometimes not practical but peaks can be captured and stored for slow release back to the system. In storms of two year frequency or less, CEI recommends that all runoff be infiltrated instead of leaving the site. Model bylaws geared towards water supply protection are included in Appendix H.

Prevention Method 2: Buffer Zones

In addition to providing pervious areas for recharge, buffer zones can filter poor water quality from highly urbanized sites such as commercial developments, subdivisions, and industrial land uses.

Although the distance of a buffer for pollutant removal varies considerably from site to site based on site-specific conditions, as outlined in Section 7.0, a general guideline would be to use a minimum 400' buffer around the chain ponds and a 200' buffer from the Ordinary High Water (OHW) mark from all tributaries and wetlands that are directly tributary to the chain ponds. This is consistent with the Cohen Bill that was recently passed in

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Massachusetts for the protection of water resources. This bill prohibits alternations to land or building within 200 feet of a tributary or other waterbody or within 400 feet of a reservoir. A summary of the Cohen Bill is included in Appendix I.

It should be understood however, that a different buffer may be appropriate depending on the site-specific conditions. For example, on steep slopes a larger buffer may be needed while in some areas where extensive infiltration is used and mature native forest is left in place, a lesser buffer may be appropriate. In any case, the buffer must not become channelized and provisions must be taken before the development occurs to protect it from short-circuiting.

In order to preserve the integrity of buffer zones created for the protection of water quality, the steps identified in Table 9-4 should be incorporated into the buffer zone requirements.

Additionally, a "demonstration buffer zone" should be developed by Pennichuck Water Works to provide an example for developers, Planning Boards, and Conservation Commissions. This could be done in conjunction with Pennichuck's review of a commercial or residential development where the developer wishes to perform a community service and stand as an example of environmentally friendly practices while incurring little or no increased cost.

Prevention Method 3: Minimize Transportation Impacts

As noted previously, transportation impacts are significant because of the number and size of the roadway network within the watershed. As development occurs in the future, additional impacts are likely to occur. To minimize these impacts, the following steps are recommended:

- Work with Public Works Departments and the State Department of Transportation to avoid direct piping of runoff to streams and instead use infiltration technologies. Grassed swales are already used in many areas, and can provide a very effective water quality improvement if stormwater is allowed to infiltrate. These groups should also be encouraged to use leaching catch basins where possible in their own construction efforts. These have been used in many areas, including along Route 101A, with a high level of success and good results.

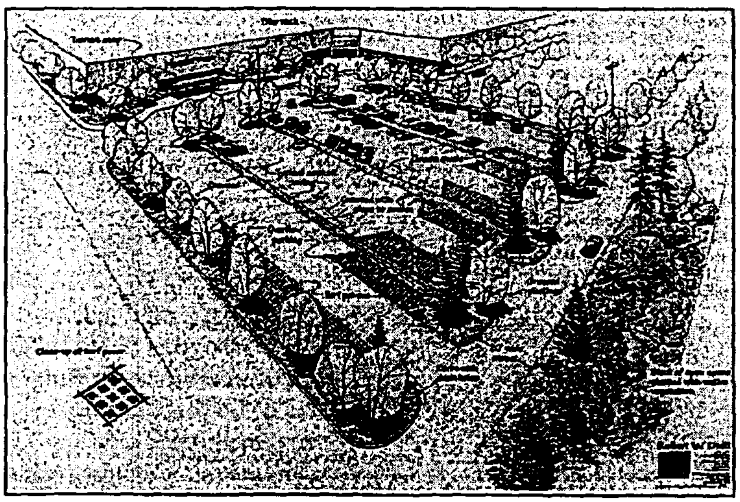

Figure 9-1. Commercial Parking Lot Using Infiltration Methods. Adapted from Schuler, 1994.

- Work with watershed Fire Departments to address spill

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issues and to make them aware of spill potential and critical watershed areas. Fire Departments should be equipped with catch basin covers, pads for solvents, caustics and acids, and booms and pads for petroleum products. Additionally, the Fire Departments should all have maps that show the locations of critical catch basins, or ideally, the most important catch basins should be marked because of the problems with keeping track of maps during emergency conditions.

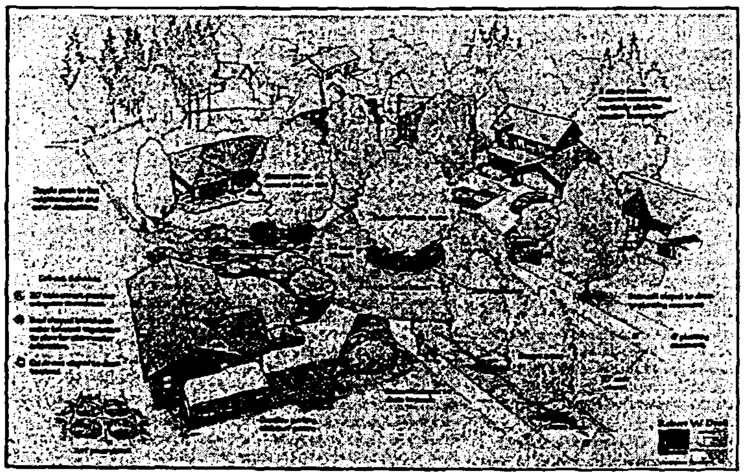

Figure 9-2. Cluster Housing Adapted to Promote Infiltration. Adapted from Schuler, 1994.

- Develop a monitored "demonstration roadway" for comparison to an existing similar but old style roadway. In conjunction with the demonstration buffer zone, Pennichuck should also develop a demonstration roadway that can be monitored as part of the monitoring program discussed in Section 9.3. The roadway should contain items such as a grassed swale mowed to a longer grass length or planted with low maintenance, low profile vegetation. If in a wet area, the swale might be replaced with a small wet pond. The purpose of the demonstration project would be to show developers, their engineers, and Planning Boards and Conservation Commissions how roadways can be developed in a more environmentally friendly method. It could also be used as a tool to work with Public Works Departments in the use of alternate technologies and narrower road widths than are typically allowed by Public Works Departments.

Prevention Method 4: Education

There are a number of education issues that need to be addressed:

- Education of general watershed residents on how their actions affect the watershed and how they can help.
- Education of school age children as tomorrow's customers.
- Education of planning boards, conservation commissions, public works departments, developers and site engineers.

In order to address these three broad classes of people, a multipart program is recommended, consisting of the following elements.

1. **Initial educational questionnaire** sent to all watershed residents regarding the current status of their knowledge and asking questions that will impart information even if the survey questionnaire is never returned.

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2. The development of **a school age public education program** with materials made specifically for the watershed and taught in gradewide presentations by a part-time professional teacher or waterworks staff, or incorporated into the school curriculum.
3. Hold a **technical transfer workshop** for Conservation Commissioners, Planning Board members and staff, Public Works directors and staff, developers and site engineers. Many of the techniques and principles may be unfamiliar, so it is important to provide educational opportunities and to obtain input from affected parties such as developers. The workshop would also allow an opportunity to discuss cost implications with developers, which are typically minimal or non-existent. In fact, many of the infiltration technologies and methods described above are lower cost than conventional methods used today. If the workshop is successful, Pennichuck could consider making it an annual event for as long as important information needs to be transmitted to developers. It could also be an opportunity to do onsite visits and reviews of Pennichuck's demonstration projects.
4. Conduct a **follow-up questionnaire survey** to gauge the effectiveness of the program and develop an understanding of how attitudes have changed or increased in knowledge.

Prevention Method 5: Modify Watershed Regulations

The existing watershed regulations have few controls that are currently beneficial to protecting the watershed. Pennichuck should begin the process of reviewing and revising these regulations to incorporate a level of protection should it be needed in the watershed. While most watershed Towns have shown a high level of cooperation, the watershed regulations could be used as a backup if practices that are detrimental to Pennichuck's water quality can not be modified through discussions and technology transfer. In most cases, however, the use of watershed regulations for enforcement of requirements should be avoided. Wherever possible, cooperative agreements should be used instead.

Remedial Actions

The remedial actions recommended below address the most highly contaminated areas of the watershed. In these areas, less expensive/intensive prevention measures are ineffective or inapplicable. These remedial measures have been developed based on specific problem areas identified in Section 9.1 Findings.

Remedial Measure 1: Dredging of the Ponds

It is strongly suspected that the Pennichuck ponds have begun to fill with sediment due to the high level of stormwater entering the watershed. Stormwater is typically laden with sediments, and these are settled out in the ponds, which are believed to provide a major improvement to the water quality that eventually reaches the treatment plant and Pennichuck's customers. Some of the ponds show particular evidence of filling with sediments, and may even be acting as sources of additional nutrients

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because of anaerobic conditions and the re-release of nutrients and other pollutants from the sediments that occurs under anaerobic (without oxygen) conditions. Because this could drastically accelerate water quality deterioration in the watershed, maintenance dredging of the ponds is probably going to be likely. However the first step in determining where and how much dredging is required is to evaluate sediment depths and characteristics. The following steps are recommended.

1. Map and probe sediments in each of the ponds for depth and extent. Take sediment samples for analysis, and measure water quality at the time of depth probes to determine whether bottom conditions are anaerobic.
2. Calculate total sediment depth and cubic yardage for potential removal.
3. Identify method of dredging and methods for dewatering dredged spoil materials or re-routing water during dry excavation.
4. Obtain approvals for dredging, which may be difficult in some instances. Show Conservation Commissions evidence of extreme need for dredging, if sediment depth probes show that it is necessary.
5. Continue to monitor ponds on a yearly basis, monitoring sediment depths at a specific location near the outlet of each pond. Use this to determine when maintenance dredging is required.

Remedial Measure 2: Infiltration Controls at Specific Sites

The most developed portions of the site are the Boire Field Brook subwatershed at 36% impervious, the Pennichuck Brook to Bowers Pond subwatershed (PBB) at 29% impervious, and the Witches Brook East (WBE) subwatershed at 23% impervious. Note the major difference in imperviousness between these subwatersheds and those with the least imperviousness, which include Witches Brook South (WBS) at 5% impervious and the Muddy Brook subwatershed (MB-1) at 6% impervious.

Although prevention methods are recommended for watershed-wide application, in many of the subwatersheds that are more developed there is little new development that can occur. It is thus likely that the prevention methods described above will have the most impact in maintaining water quality in those less developed watersheds, where they will have a lesser impact in the developed watersheds. The more developed watersheds, or those with higher imperviousness, are more likely to be affected by remedial measures. Therefore, it is these subwatersheds that are most appropriate for the use of structural Best Management Practices (BMPs).

These technologies are appropriate for projects that come back to the Planning Board for substantial modification of existing facilities, or expansion of those same facilities, or as stand alone units such as the one developed by Pennichuck for New Hampshire Technical College.

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An additional structural BMP was created for the Pennichuck Square area. Both of these BMPs are located within the most impervious subwatershed of Boire Field Brook. An additional structural BMP within this area that should be considered is one to control runoff from the airport. Airports are well known for their contribution of spills of aviation fuel, oil and deicing chemicals to waterways. Additionally, they commonly produce a heavy nutrient load and heavy metal load from the same sources as found on other types of roadways. This type of land use essentially presents itself as a huge parking lot, and the impacts on local waterways can be significant. We recommend that Pennichuck work with the Boire Field authorities to develop a BMP that will assist in reducing the impacts of this airstrip on Pennichuck's water supply. Once all the BMPs are completed in the most highly impervious subwatershed, the next most highly impervious subwatershed (PBB-Pennichuck Brook to Bowers Pond) should be addressed.

By addressing the most impervious watersheds with remedial measures, steps can be taken each year to reduce the impact of these most impervious areas on water quality. A ranking of the areas in terms of appropriateness for remedial measures is given on Table 9-4.

Remedial Measure 3: Hazardous Waste Sites

There are a number of hazardous waste sites in the watershed, some more benign than others. These sites are in various stages of remedial action being required by DES, but these processes can often be expedited if water supplies are at risk. We recommend that Pennichuck request a status report on each of the sites. Their status at the time of this report is recorded in that information, however, at least an annual discussion with each of the project managers at DES on each of the sites should be conducted to make sure that DES is aware of Pennichuck's Watershed Protection Program and that Pennichuck is aware of DES' most recent actions on the site.

Remedial Measure 4: Hot Spots

Hot spots are defined in this report as service stations, car dealerships and automotive repair shops. Because of the potential of these particular types of businesses to create major water quality impacts on the system as a whole, special educational efforts are warranted. Service stations can generate significant hydrocarbons, metals, and other pollutants from car washing, engine steam cleaning, spills of oil and gas, parts cleaning, leakage from wrecked vehicles and exposure of automotive products and waste to stormwater. Since most floor drains can no longer be connected to the

Table 9-4
Remedial Measures Priority Subwatersheds

Rank	Designation	Name	Location	Impervious
1	BFB	Boire Field Brook	Nashua	36%
2	PBB	Pennichuck Brook to Bowers Pond	Merrimack & Nashua	29%
3	WBE	Witches Brook East	Amherst/ Hollis	23%
4	WBN	Witches Brook North	Amherst/ Milford	19%
5	SPB	Stump Pond Brook	Amherst/ Merrimack	17%

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sanitary sewer, many gas stations discharge these materials either directly to storm drains or recharge onsite. Neither of these is acceptable and in fact are illegal in areas defined as "underground sources of drinking water". Some of the recommended pollution prevention practices

Table 9-5 Recommended Practices to Prevent Stormwater Pollution from Service Stations/Auto Repair Areas	
1	Prevent discharges when changing automotive fluids
2	Use drip pans when working on engines
3	Use special care to prevent leaks from wrecked vehicles
4	Quickly cleanup spills of all sizes
5	Keep wastes from entering floor drains and storm drains
6	Use concrete surfaces and roofing over fueling areas to prevent spilled fuel from contact with stormwater
7	Properly store and recycle used batteries
8	Clean parts without using liquid solvents (or use solvent recyclers)
9	Capture all metal particles during grinding and finishing operations
10	Properly store and recycle waste oil, antifreeze and other automotive fluids
11	Select "environmentally friendly" products and control inventory to reduce wastes
12	Keep all working areas inside and away from stormwater
13	Treat all liquid streams from car washing and engine cleaning
14	Train employees on pollution prevention activities for the shop
15	Educate customers on proper recycling and/or disposal of automotive products

identified by the Santa Clara Valley Non-Point Source Control Program are listed in Table 9-5.

Monitoring

Monitoring Technique 1: Measure Stream Channels and Imperviousness Annually

The imperviousness estimates made for this project, which was shown on Table 9-2, should be updated on an annual basis based on the amount of imperviousness added in each subwatershed. There are several methods to estimate this, which could include additional land use mapping or aerial photography, or the development of town by town "imperviousness" budgets that could be calculated by Planning Boards after each calendar year. Several locations along the main stream channel should also be selected to survey in channel characteristics. This could then be measured on an annual basis, or alternatively, aerial photographs could be used to calculate annual changes in key subwatersheds.

Monitoring Technique 2: Periodic Sediment Depth Mapping

As described in Remedial Measure 1, sediment depth mapping of the ponds is needed to evaluate their current status. This should also be continued on an annual or bi-annual basis to determine the rate of accumulation.

Monitoring Technique 3: Stormwater Monitoring of Demonstration Projects

The demonstration projects already undertaken by Pennichuck should be monitored upstream and downstream for at least three storms per year to evaluate the effectiveness of the measures. This should also be done at the demonstration buffer project and the demonstration roadway projects when completed. This pre- and post-monitoring of control areas and up and downstream areas of the demonstration projects will allow for corrections to be made if necessary and will demonstrate the effectiveness of the methods.

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Monitoring Technique 4: Intensive One Year Monitoring Program

Because there is little water quality baseline for the watershed, a baseline-monitoring program should be developed over a one-year period.

Dry Weather Monitoring

The purpose of a monitoring program is to provide critical long-term trending information for the chain ponds and their tributaries. The data obtained from the monitoring plan will identify the current in-pond water quality and assist in evaluating the impacts of the surrounding watershed on the chain pond system.

Since there is very limited data on watershed water quality, it is recommended that a monitoring program be implemented with monthly monitoring including depth sampling in each of the ponds and tributary sampling in each subwatershed. It is recommended that three samples be taken at each pond to establish whether in-pond sediments may be providing a source of phosphorus and other chemical loadings to the ponds and to provide more information on possible corrective methods. Only ponds that show stratification should be sampled in this way. Shallow ponds (typically less than 10 feet deep) that don't stratify should be sampled at top and bottom only, in the deepest section of the pond. The first should be taken at the water surface in the epilimnion layer. The second should be taken in the metalimnion layer, and the third should be taken a few inches from the bottom of the reservoir in the hypolimnion layer. The parameters recommended for analysis are provided below:

- ❑ Ammonia nitrogen - This is the nitrogen form most readily used by aquatic plants. Nitrogen may contribute to excess vegetative growth in a water system. High levels of ammonia nitrogen may indicate a nearby source of waste discharge or fertilizer storage. A method detection limit of 0.05 mg/l may be used for ammonia nitrogen analysis.
- ❑ Chloride - Chlorides may be introduced to runoff after salts are applied to remove ice and snow from roads, parking lots and sidewalks. At high levels, chlorides can be toxic to fresh water organisms. A field probe may be used for measurement.
- ❑ Dissolved oxygen* - Dissolved oxygen levels will indicate if bottom sediments have an oxygen demand. A field instrument should be used and calibrated before the readings are taken. High dissolved oxygen levels may cause algal blooms, which can lead to fish kills, and other undesirable water quality effects.
- ❑ Fecal coliform* - Indicator of disease causing pathogenic organisms. The laboratory should use the membrane filter method. The presence of fecal coliform is typically an indication of nearby feces from animals or humans.
- ❑ Nitrate - A method detection limit of 0.05 mg/l may be used for nitrate nitrogen. High nitrate levels may indicate contamination from fertilizer, municipal wastewaters, feedlots, or septic systems.
- ❑ pH* - A field probe may be used for measurement. Over-

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productive reservoirs or ponds may see fluctuations in pH as vegetation photosynthesize and respire.

- Specific conductivity - Specific conductivity is a field measurement of the amount of particulate within a sample. A field probe may be used for measurement. Conductivity is also a measure of total dissolved solids, which are carriers for contaminant sources in water.
- Temperature* - Temperature can be used to identify the epilimnion, metalimnion and hypolimnion layers in the reservoir depth samples. A field probe may be used for measurement. Variations in temperature may be an indication of wastewater discharges.
- Total dissolved solids (TDS) - TDS are also carriers for phosphorus and other contaminant sources. A field probe may be used for measurement.
- Total Kjeldahl nitrogen (TKN) - A method detection limit of 0.20 mg/l may be used for TKN analysis. High TKN values may indicate the presence of a nitrogen source such as a feedlot or wastewater discharge.
- Total phosphorus* - This is the limiting nutrient in a fresh water system and may result in excess algal growth if present in sufficient quantities. A method detection limit of 0.01 mg/l should be used for total phosphorus analysis. The laboratory should be contacted before sample collection to see if they can analyze to this detection limit. They may require a larger sampling container for the lower detection limit.
- Total suspended solids (TSS)* - TSS are carriers for phosphorus and other contaminant sources. A field probe may be used for measurement.
- Turbidity* - Elevated turbidity levels can interfere with disinfection by sheltering microbes and reducing their exposure to chlorination, potentially allowing disease causing pathogenic organisms to enter the distribution system. A field probe may be used for measurement.

**Analyzing the chain ponds at these depths for the parameters indicated above with an asterik (*), will help establish whether there is a phosphorus loading from the sediments of the ponds.*

In addition to the pond depth sampling, it is recommended that quarterly sampling be conducted at seven tributaries to assist in determining the impacts the surrounding watershed has on the chain pond system. Location of these sampling points can be seen in Figure 9-3.

It is recommended that each of these samples be analyzed for the parameters indicated in the list above. Additionally, flow rates should be taken from all streams monitored. Review of the long-term monitoring data over a few sampling runs may allow for the reduction of some parameters such as nitrate-nitrogen.

Stormwater Monitoring

To evaluate the degree of pollution associated with stormwater in this

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watershed, a wet weather sampling program using a "cluster" design was developed. Sampling locations were chosen to collect stormwater runoff from various types of land uses within the watershed including residential, industrial and commercial. Both stormwater drainage maps and land use maps were used in choosing the locations. Sampling locations in each land use were chosen based on the stormdrain pipes that drained the largest area to ensure enough flow for the analysis. Identified sampling locations are shown on Figure 9-4 and are identified in the appendix.

The equipment needed to complete the sampling will include plastic gloves (no zinc), acid washed sampling bottles, acid washed pail, stop watch, watch (with minute hand) and rain coats, which are discussed in more detail under the sampling procedure. All samples should be analyzed for:

- ❑ Total Phosphorus
- ❑ Nitrogen (TKN)
- ❑ Heavy metals including lead, copper, zinc, chromium and cadmium
- ❑ Chloride
- ❑ Total Suspended Solids
- ❑ Volatile Suspended Solids
- ❑ Oil and grease
- ❑ Conductivity
- ❑ pH
- ❑ Total Coliform
- ❑ Fecal Coliform

The procedure for collecting stormwater samples should be as follows:

1. Teams of two people will be on site at least 30 minutes before rain starts. All team members should wear zinc free gloves to prevent sample contamination.
2. Sampling will begin when the flow of water starts (approximately one to two inches of water in pipe).
3. An acid washed bucket will be used to collect the sample from the drainpipe. Buckets will be rinsed three times between samples. Samples will be gathered in an acid washed bucket and distributed in appropriately labeled containers.
4. The following field parameters should be taken at each sample:
   - Time
   - Flow rate
   - Depth of water in pipe
   - Diameter of pipe
5. Samples will be taken every 30 minutes for two hours. A total of four samples per site should be taken.

It is important to have reasonable weather data to properly plan for stormwater sampling. Storm notification can be obtained from the Channel 9 Manchester Weather Station WMUR at (603) 669-9999, or from National Weather Service in Gray, Maine (One Weather Lane, PO Box 1208, Gray, ME 04039-1208) with real time radar at (207) 688-3216 from 7:00 am to 5:00 pm. The National Weather Service in Gray, Maine is the most accurate and can usually predict a storm one to two hours before rain starts.

Late summer (July/August) sampling is recommended to provide a worst case event, preferably after a week long dry period so contaminants are built up on surfaces.

An alternative to this type of labor-intensive sampling would be to install a datalogger at specific locations,

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potentially with a sampler. However, not all parameters can be measured with this method.

Monitoring Technique 5: Follow-up Monitoring

Once the one year intensive baseline of dry weather and stormwater monitoring has been completed, trend graphs can be developed and evaluated. Some parameters may be dropped, others could potentially be added. The monitoring in the same locations should then continue for the long-term, using a quarterly baseflow monitoring, and periodic stormwater monitoring of demonstration projects and key areas identified during the baseline program. This program would then continue indefinitely, updated annually to determine the effects of the Watershed Management Program on water quality. It can also be used to monitor the progress in meeting the overall goals and objectives of the project.