A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Aquifers

Updated Methodology & Data

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A Project of the
Society for the Protection of N.H. Forests
Land Protection Department

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TABLE OF CONTENTS

	Page
Acknowledgments	3
Executive Summary	
Background	4
Study Focus Area	4
Overview of FGWA Method	5
Findings	6
Recommendations for Further Enhancement	7
Section 1: Introduction	
Background	9
Caveats	10
Terminology	11
Section 2: Methodology	
Buffer Regimes	13
Transportation Features	14
Hydrological Features	16
Known and Potential Contamination Sites	17
Other Urban Features	19
Section 3: Results of the Updated Model	
Overview	21
Geographic Distribution	23
Protection Status	25
Section 4: FGWA Data Trends 2002 to 2010	
New Roads and Ancillary Development	30
Tracking Urbanization	32
Section 5: Summary	
Fraction of a Fraction	35
Recommendations for Further Enhancement	36
Appendix A: About Stratified-Drift Aquifers	38
Appendix B: USGS Stratified-Drift Aquifer Mapping	41
Appendix C: Tables of NHDES Project Types and Acronyms	44
Appendix D: Aquifer Transmissivity and Potential Well Yield	48
Appendix E: Map Disclaimer	51
Appendix F: GIS Operator Data	52

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EXECUTIVE SUMMARY

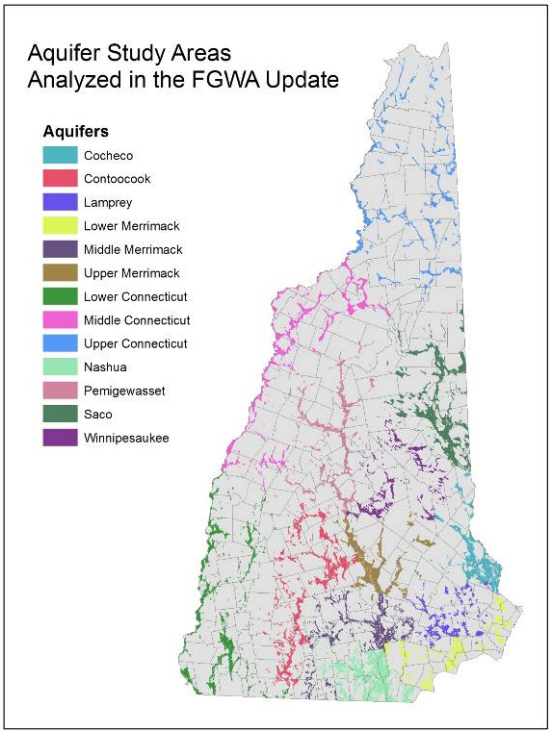
Background

This is the third in a series of publications describing the N.H. Department of Environmental Services' Favorable Gravel Well Analysis (FGWA) methodology, and as such, represents the first comprehensive update of the data and the geographic information system (GIS) spatial data since approximately 2002.

The first efforts to delineate those areas of our stratified-drift aquifers with greatest potential to provide future municipal water supplies are documented in *A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Aquifers, Volume 1*, which was released January 1999, after more than a year of study by NHDES staff working with an ad hoc advisory committee that provided expert recommendations regarding technical issues.

A second report, *Volume 2 GIS Operators Manual*, was developed in tandem with Volume 1, and also released in January 1999. This report focused on the GIS data and processing necessary to conduct the analysis, and was used as core guidance in conducting the update of the FGWA for 2010 by the Forest Society.

In 2009, the Forest Society contracted with the NHDES to update the favorable gravel well analysis, and to help make the information available via various media. The partnership of the Forest Society and NHDES dates back more than a decade with collaboration on a variety of projects aimed at better understanding the growth pressures impacting the critical water supply resources in the state, and building a case for accelerated protection of those resources in the face of development.



Study Focus Areas

The data developed for the 2010 FGWA update covers thirteen stratified-drift aquifer study areas[1] statewide. These aquifers total more than 805,000 acres of land, or about 14% of the land area of New Hampshire. The map at the right shows the extent and distribution of the aquifers.

Overview of the FGWA Method

[1] Stratified-drift aquifers are comprised primarily of sand and gravel, and in places contain significant quantities of groundwater useful for municipal water supply.

The approach used in the FGWA is based on a series of overlays of buffered features. Four suites of buffers are developed in the GIS processing, each with its own unique buffer distances. These regimes include:

- Transportation Buffers
- Hydrological Buffers
- Known and Potential Contamination Sites
- Urban Features

The buffer distances used vary from 50 feet to 1,000 feet depending upon the feature being considered. However, a core concept of a ***sanitary protective radius*** (SPR) is key to many of the buffer distances used in this update. The sanitary protective area is a zone surrounding a community water supply well that is required (*N.H. Code of Administrative Rules Env – Dw 302* for large community wells) to be controlled by the water supplier and maintained in a natural state to minimize the risk of groundwater contamination. The sanitary protective area is a circle centered on the well, the radius (SPR) of which varies according to the approved pumping rate of the well.

This study focuses on wells producing at least 75 gallons per minute (gpm) appropriate for municipal water supply; data are also presented for very high-yield wells of 150 gpm or greater. A well permitted to produce 75 gpm is required to have an SPR of 300 feet and a well permitted to produce 150 gpm is required to have a 400-foot SPR.

In this study, buffer distances are as follows:

- Roads and highways are buffered by the appropriate SPR plus ½ the approximate right-of-way to allow for the actual travelway.

- Hydrological features (lakes, ponds, rivers, wetlands) are buffered at 50 feet.

- Known and potential contamination sites are buffered by the appropriate SPR, or 1,000 feet for certain types of known contamination sites.

- Urban features (pipelines, transmission lines, railroads) are buffered by the appropriate SPR plus ½ the approximate right-of-way.

None of these buffers guarantees protection from contamination, but they do allow a first-cut analysis of land availability for municipal well location. FGWA studies are encouraged at community scale, and buffers may be modified to reflect local knowledge, updated hydrologic science or knowledge of local groundwater conditions, or interpretation of NHDES regulations (for example, a buffer for a closed, but unlined landfill could be increased to a higher buffer distance than the sanitary radius).

<u>Findings</u>

In general, the updated FGWA shows that ***only about one-quarter to one-third of all the sand and gravel aquifer land area statewide remains*** after the groundwater quality-based buffering process outlined above. And, of that remaining area, only a fraction is suitable for large municipal well development on the basis of potential yield.

Several key statistics are listed below in a hierarchy to illustrate the scarcity of this groundwater resource in New Hampshire, and the relatively low level of permanent land protection in key high-yield aquifer areas.

- The total area of the mapped stratified-drift aquifers in New Hampshire is about 805,500 acres, or ***only 14% of the state's land area.***

- Across the state, only about 246,000 acres, or 30% of the total aquifer area, remains after buffering threats to groundwater quality for wells pumping 75 gpm or more. ***Only 84,576 acres, or 34%, of the 246,000 acres*** has sufficient yield to be suitable for municipal water well development of 75 gpm or greater.

- Only 209,000 acres, or 26% of the total aquifer area remains after buffering potential threats to groundwater quality for wells pumping 150 gpm or more. ***Only 25,000 acres, or 12% of the 209,000 acres*** appears to be suitable for wells pumping 150 gpm or greater.

- For wells pumping 75 gpm or greater, ***only about 17,300 acres, or 21%*** of favorable well site land is protected.

Detailed figures are summarized in the table below, and later in the report.

	SPR 300		SPR 400	
Yield Class	**Acres**	**Percent of Total Area**	**Acres**	**Percent of Total Area**
<75 gpm	130,324.1	53.0%	110,537.9	52.9%
>=75 gpm but <150 gpm	55,176.4	22.4%	45,135.9	21.6%
150 gpm	2,896.8	1.2%	2,414.5	1.2%
>=150 gpm but <300 gpm	15,664.2	6.4%	13,357.4	6.4%
>=150 gpm but upper limit unknown	50.5	0.0%	38.0	0.0%
>=300 gpm	10,787.9	4.4%	9,146.1	4.4%
Undefined	31,166.7	12.7%	28,282.8	13.5%
Total area outside buffers	**246,066.6**		**208,912.6**	
Total area outside buffers with sufficient yield	**84,575.8**	34.3%	**24.956.0**	11.9%

Note: The green-shaded areas of the table represent aquifer areas with adequate transmissivity for high-yield (SPR 300) and very-high_yield (SPR 400) wells.

The 2010 update produced two other important findings relative to encroachment on the aquifers. First, ***approximately 19,600 acres of aquifer area suitable for municipal well development in***

2002[2] has been lost to development with roads and residential housing of varying densities or industrial/commercial facilities. That amounts to ***more than 30 square miles of aquifer land area in eight years.***

Second, ***the data show only 325 additional acres were impacted from 2002 to 2010*** in comparing the change in land area buffered for known and potential contamination sites on aquifer land area.

Recommendations for Enhancement

Experience with this 2010 update of the NHDES favorable gravel well analysis has pointed to several issue areas, which if addressed in future studies, would greatly improve the accuracy of the calculation of available aquifer area for new well sites and provide a better baseline for tracking trends statistically and spatially.

NHDES Database: The NHDES database for known and potential contamination sites is complex and ever-changing, but the data are not catalogued chronologically in terms of when the feature has been added to the database, or when the project has been closed (remediated) by NHDES. At this time, we can only see the present condition in the data available. With a time series in the data, long-term trends can be better evaluated.

Aquifer Mapping: In the course of this project, discrepancies in the mapping of two adjoining aquifer study areas in southeastern New Hampshire originally mapped by USGS were discovered that affect the results of the model. While adjustments were made for this study based on comments from USGS, corrections to the mapped data will require additional attention.

Another, much larger project is to update the mapping in the Nashua aquifer study area. Generalizations within the higher transmissivity contours (please see Appendix D for an explanation of hydrogeological terms) make it difficult to determine the potential yield threshold for wells pumping at 75 gpm or greater, and very likely overstates the aquifer area suitable for municipal well development. This is the oldest of the thirteen aquifer maps (1987), but covers one of the most rapidly urbanizing regions in the state, and so should be a priority for updating.

Current Land Use Data: The buffering protocol used in the FGWA depends a great deal on the NHDOT road and highway data as a proxy for a variety of land uses not detected by other means. This "first cut" analysis is appropriate for statewide or region-wide assessments, but as is noted earlier in this report, the accuracy of the favorable well site delineation is much greater when land use data are available that show what is actually happening on the ground at a given time. An ideal resource would be regional or statewide land use mapping.

Upgraded Urban Features Data: It would be helpful, and increase the accuracy of the FGWA delineation, to establish the actual right-of way distances for these features, and generate a buffer data layer for use by planners and GIS operators in conducting local versions of the analysis.

[2] 2002 was the last update of the Favorable Gravel Well Analysis data.

Adding other urban land use features, such as cemeteries, gravel mining operations, etc., would also strengthen the usefulness and accuracy of the dataset.

Delineation Accuracy: In comparisons with aerial photography, this study finds that the use of road buffer proxies for development on aquifers over-states the unconstrained land area suitable for new municipal wells. Even with better land use data, there is no replacement for detailed evaluation of land use boundaries using aerial photography. This level of detail and accuracy is especially important to community-scale planning, and is consistent with other data development and planning services available in the public sector (regional planning agencies) and in private consulting services.

Section 1: INTRODUCTION

Background

This is the third in a series of publications describing the N.H. Department of Environmental Services' Favorable Gravel Well Analysis (FGWA) methodology, and as such, represents the first comprehensive update of the data and the geographic information system (GIS) spatial data since approximately 2002.

The first efforts to delineate those areas of our stratified-drift aquifers with greatest potential to provide future municipal water supplies are documented in *A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Aquifers, Volume 1*, which was released January 1999, after more than a year of study. Originally known as the High Value Groundwater Project, this guide was developed by NHDES staff working with an ad hoc advisory committee that provided expert recommendations regarding all technical issues that arose, including the appropriate buffer distances for various known and potential contamination sources. The town of Henniker was used as a pilot study area to test the GIS methodology used, but the purpose of the analysis and the report was to develop a means to identify portions of aquifers with greatest potential for future use as municipal water supply sources with a view to protecting them to ensure their future availability.

A second report, *A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Aquifers, Volume 2 GIS Operators Manual*, was developed in tandem with Volume 1, and also released in January 1999. This report focused on the GIS data and processing necessary to conduct the analysis, and was used as core guidance in conducting this update of the FGWA for 2010 by the Forest Society.

Both of these reports contain valuable technical insights and methodological guidance to anyone wishing to conduct a favorable gravel well analysis, and should serve as references. Key material from these reports is included in the Appendices of this report. Both Volumes 1 and 2 are available from the NHDES Drinking Water Source Protection Program.

In 2009, the Forest Society contracted with the NHDES to update the favorable gravel well analysis, and to help make the information available via various media. The partnership of the Forest Society and NHDES dates back more than a decade with collaboration on a variety of projects aimed at better understanding the growth pressures impacting the critical water supply resources in the state, and building a case for accelerated protection of those resources in the face of development. For more background on this collaboration, refer to *Our Drinking Water Lands in New Hampshire: Research Highlights*, released October, 1998, and available at http://www.forestsociety.org/pdf/drinkingwater.pdf.

The Forest Society's interest in protecting our water resources is part of a much larger vision for conservation of key natural resources statewide. Titled *New Hampshire Everlasting*, this strategic vision statement was crafted in 2001, and spans five major goals relating to suites of natural

resources: forests, wildlife, agriculture, water, and community legacy values. Protection of drinking water resources is specifically defined under the water resource goal[3], as follows:

Goal Four: Conserve Lands that Keep our Water Clean

Protect water quality and aquatic ecosystems by:

- *Conserving remaining undeveloped source lands for existing public drinking water systems and new lands necessary to supply the anticipated population many generations from now.*
- *Buffering water courses and wetlands from development with natural vegetation.*
- *Preventing development of more than 10 to 20% of each watershed with pavement and buildings.*

As part of *N.H. Everlasting*, the Forest Society has developed an extensive spatial and statistical database of natural resources in the state, their protection status, and the growth pressures impacting these resources. From time to time, this database – called *New Hampshire's Changing Landscape* – is updated and trends are reported out. In the first publication of this data in 1998, critical water supply lands played a central role in the assessment, but the time was too early to included work just being done on the favorable gravel well analysis by NHDES.

Now, the Forest Society has stepped forward to help develop the 2010 FGWA update, to include discussion of this critical groundwater resource in *N.H.'s Changing Landscape*, and to promote better understanding and stewardship of our groundwater resource by making this information accessible to a wide user group, including online media resources.

Caveats

The following ***Map Disclaimer*** is included in *Volume 2* of the FGWA publications discussed above. As such it lays out important acknowledgements of the limitations of the data used in this study, and the manner in which the data should be interpreted and used. A slightly updated version of the disclaimer is found in ***Appendix E***, and is intended for use on any maps or other publications produced using the NHDES FGWA method.

"This map represents digital data available from state and federal agencies as of June 1998. It shows a computerized overlay analysis to determine areas of stratified-drift aquifer potentially having both water yield and quality sufficient to serve as large public water supplies. Local land use information and further hydrogeologic analysis are essential to determine the suitability of any location as an actual well site. Buffers used to create this map do not guarantee protection from

[3] For more information on N.H. Everlasting and the Forest Society's strategic conservation vision, see http://www.forestsociety.org/pdf/nheverlasting.pdf

well contamination. The status of sites and associated buffers are subject to change when contamination has been cleaned up. Similarly, the existing source water protection areas may be revised as more site-specific hydrogeologic information becomes available.

The information provided in this map includes a subset of databases developed by the New Hampshire Department of Environmental Services. Development of these databases is ongoing and this map may not contain all existing and potential threats to groundwater. NHDES is not responsible for the use or interpretation of this information, nor any inaccuracies in site names, locations, projected yields, or groundwater flow direction. All information is subject to verification. The data are intended for use at 1:24,000 scale. These data are to be used for planning or educational purposes only. The production of this map was performed under the auspices of the New Hampshire Comprehensive State Groundwater Protection Program with funding support from EPA Region I - New England."

It is important to recognize the limitations of the data used in this study, and to understand the useful application of the resulting favorable gravel well analysis. The FGWA protocol depends upon best available statewide data in order to delineate those areas on the aquifer formations with best potential for municipal water supply. The currency of the data varies from one dataset to another, and the accuracy of the data as compared to actual on-the-ground conditions will vary accordingly. Furthermore, the use of buffers in the methodology is only a general allowance for modeling purposes, as opposed to reflecting site-specific conditions; the mosaic of land uses that can and do impact groundwater quality is much more complex than any buffering approach can provide, and no replacement for careful study at community scale.

Finally, the reference to 1:24,000 scale in the NHDES disclaimer is important, and all GIS operators are aware that these data become less reliable geographically as mapping trends downward to site scale. None of the datasets used in this analysis should be used for actual site evaluations for well siting; rather, they are appropriate for town-scale planning efforts, or regional or river basin-wide aquifer studies. Any investment in well siting studies should be based on professional hydro-geological and engineering inputs, as well as thorough site condition data-gathering and evaluation.

Terminology

While acronyms are avoided as much as possible in this report, in some cases the flow of information is improved by using short-form references. The acronyms are noted parenthetically when the full terminology is first used, or footnoted where isolated references occur.

There are some key terms that should be explained as standards in this report, however. Note that the terms below intend to communicate a hierarchy of scales, including the entirety of the aquifer land base for context, the land remaining after applying water quality protection buffers, and finally, the actual land area suitable for municipal water wells producing at a rate of at least 75 gpm.

> **SDA** stands for **stratified-drift aquifer**, explained in detail in Appendices A and B of this report.

High-yield SDA refers to SDA with suitable transmissivity to support a municipal well of 75 gpm or greater.

FGWA translates as **favorable gravel well analysis.** This term is used to refer generally to the modeling process or the data derived from the model, and not the land areas suitable for well development.

SPR stands for **sanitary protective radius**, also explained in detail in the Methodology section of this report.

SPR 300 and 400 mean the gross land area of SDA remaining after removing areas that are unfavorable due to quality reasons, by applying buffers as required for 75 gpm or greater pumping rates, or 150 gpm or greater in the case of SPR 400.

FGWA 300 means favorable gravel well areas with potential for municipal wells pumping at a rate of **75 gpm, or greater after removing areas that are unfavorable due to quality (buffers) and yield (transmissivity) considerations.** These are referred to as suitable for ***high-yield wells*** in the report.

FGWA 400 means favorable gravel well areas with potential for municipal wells pumping at a rate of **150 gpm, or greater after removing areas that are unfavorable due to quality (buffers) and yield (transmissivity) considerations.** These area are referred to as suitable for ***very high-yield wells*** in the report.

Section 2: METHODOLOGY

This section of the report covers the data and methods used to delineate the favorable gravel well areas for each of thirteen river basins in the state.[4] To avoid highly technical discussion of GIS processing, the goal of this narrative is to be descriptive as to elements of the analysis, and to offer qualifiers where appropriate. **Appendix F** contains an overview of the data used in the FGWA, its sources, and the technical processing used.

Note that it is not necessary for users of the GIS data to actually replicate the method. For the time being, the various buffers described below are available to GIS operators for their own studies by contacting the NHDES Drinking Water Source Protection Program. As NHDES and NHDOT data are updated, the stepwise description of methods in the appendix will be useful in guiding reconstruction of the buffers for contamination sites and road buffers.

Buffer Regimes

The approach used in the FGWA is based on a series of overlays of buffered features. Four suites, or regimes, of buffers are developed in the GIS processing, each with its own unique buffer distances. These regimes include:

- Transportation Features
- Hydrological Features
- Known and Potential Contamination Sites
- Urban Features

The buffer distances used vary from 50 feet to 1,000 feet depending upon the feature being considered. However, a core concept of a ***sanitary protective radius*** (SPR) is key to many of the buffer distances prescribed in the discussion that follows. The sanitary protective area is a zone surrounding a new community water supply well that is required (N.H. Code of Administrative Rules Env–Dw 302 for large community wells) to be controlled by the water supplier and maintained in a natural state to minimize the risk of groundwater contamination. The sanitary protective area is a circle centered on the well, the radius (SPR) of which varies according to the approved pumping rate of the well. While this study focuses on wells producing at least 75 gallons per minute (gpm), wells that produce at much lower rates can still be quite significant in meeting a community's water supply needs. A well permitted to produce 75 gpm is required to have an SPR of 300 feet and a well permitted to produce 150 gpm is required to have a 400-foot SPR. In this analysis, these two SPR buffer distances are applied to urban features and potential contamination sites (see discussion below).

[4] U.S. Geological Survey divided the state into 13 study areas when carrying out the stratified-drift aquifer mapping studies. With the exception of the Nashua Region study area, which corresponded to the service area of the Nashua Regional Planning Commission, the study areas corresponded to river basins.

The other two constraining buffers other than SPR distances are 50 feet for hydrological features, and 1,000 feet for known contamination sites.

None of these buffers guarantees protection from contamination, but they do allow a first-cut analysis of land availability for municipal well location. FGWA studies are encouraged at community scale, and buffers may be modified to reflect local knowledge, updated hydrologic science or knowledge of local groundwater conditions, or interpretation of NHDES regulations (for example, a buffer for a closed, but unlined landfill could be increased to a greater buffer distance than the sanitary radius).

Transportation Features

This section covers the buffers used with roads and highways. Other transportation related features, such as railroads, are included in the discussion of urban features that follows.

The protocol developed in the previous FGWA studies is that roads (mapped as the centerline of the right-of-way) should be buffered by the appropriate SPR plus ½ the approximate right-of-way to allow for the actual travelway. Right-of-way widths vary considerably depending upon when the road was constructed and whether it is located in a rural or urban context. Early roads in New Hampshire were commonly "laid out" by local governments as 3-rod rights of way, or approximately 50 feet. Modern interstate highways and state arterials obviously require wider rights of way, typically in the range of 150 feet.

New, updated N.H. Department of Transportation (NHDOT) road and highway data is now available which supersedes the earlier use of roadway centerlines derived from USGS topographic maps that were used along with early NHDOT road and highway data in the original FGWA project. This eliminates the conflicts in mapped data that occurred in using two, differing road classification systems. Use of the updated NHDOT data also allows the road network to be classified by functional class, thus making the assignment of right-of-way buffers more accurate overall. The road and highway data used in this update was released by NHDOT in February, 2010.

Table 1 below summarizes the classes of roadways, rights-of-way, and the buffer distances applied to each road functional class. This approach builds upon a similar hierarchical classification system used in the original FGWA project, and which is now included in the updated NHDOT data[5]. While ranges of right-of-way width are presented in each class, the upper end of the range is used in calculating the buffer distance to be conservative.

[5] Page 7, Volume 2 GIS Operators Manual

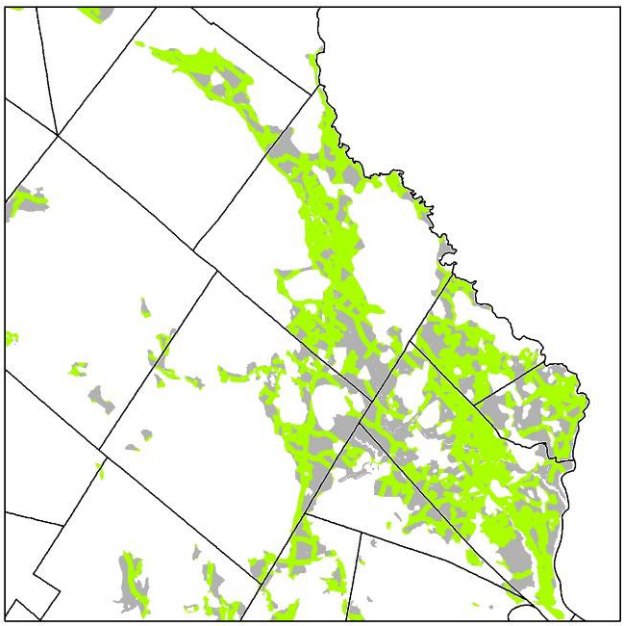
Table 1: Transportation Buffer Distances by Functional Class

DOT Functional Class	ROW	SPR 300 Buffer	SPR 400 Buffer
Interstate	100 - 150	375	475
Primary	100 - 150	375	475
Secondary	50 - 100	350	450
Municipal (Class 5)	50 - 75	338	438
Private Recreation	50 - 75	338	438
Federal	50 - 75	338	438
Recreation	50 - 75	338	438

This classification system requires multiple queries of the NHDOT data to eliminate legislative class 6 roads (closed to public travel), and to retain special classes such as federal roads (legislative class 7) and private roads. Inclusion of private roads is important since many new residential subdivisions and commercial/industrial/institutional developments maintain private roads. Private roads are also a major feature in the North Country where extensive timber interests are found. The GIS query procedure for this classification may be reviewed in ***Appendix F*.**

It should also be noted that in some urban settings, highway rights-of-way exceed the ranges given above. Using 2008 aerial photography, several of the larger interstate highway rights-of-way in southern New Hampshire were measured as a check in this project. Interstate 95 in the Seacoast has a typical right-of-way width of 275 feet and I-93 between Manchester and Concord measures 200 feet. This points to the need to refine the FGWA when evaluating local community situations.

Transportation buffers affect large areas of the SDA in nearly every region of the state. As an example, the map inset to the right shows the Rochester–Dover area in southeastern N.H, with the SPR 300 and SPR 400 road and highway buffers applied in green . The gray areas are aquifer areas not affected by road buffers.



Also see the section later in this report titled ***FGWA Data Trends 2002 to 2010*** for more details on transportation impacts on the high-yield SDA statewide.

Hydrological Features

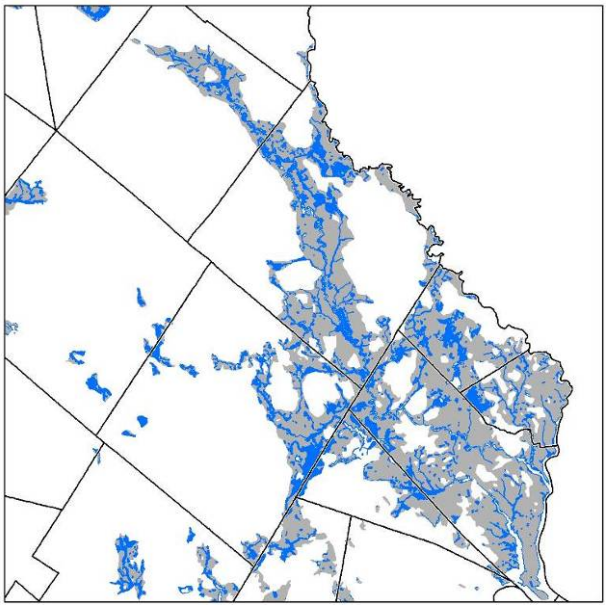
All new community sand and gravel wells are required by NHDES to be at least 50 feet from any surface water including intermittent streams, therefore a 50-foot buffer is used along all water features, including wetlands. The intent is to avoid bacterial contamination of well water.

All hydrographic features of concern are now available in the National Hydrography Dataset (NHD) published by USGS (last revised 2006), with input from the N.H. Geological Survey. Similar to the transportation buffers discussed above, this improves the accuracy of the data by obviating the need to use the streams and water features derived from USGS topographical maps. Intermittent streams can also be mapped in the buffer model, and wetlands are included in the NHD.

The wetlands component was also augmented by including the National Wetlands Inventory (NWI) data for New Hampshire. While this data is somewhat dated (1991), it classifies all wetlands by type according to the Cowardin system, and thus includes areas of forested wetlands, for example, that may not be delineated in the NHD. Coastal communities should consider also adding the coastal wetlands data developed in 1988, and offering greater detail and accuracy of wetland edge delineation.

There are three primary NHD datasets, all available from the GRANIT database at the University of New Hampshire:

- NHD Flowline, which includes all perennial and intermittent streams
- NHD Area, which includes rivers and inundation areas at flood control structures
- NHD Waterbody, which includes all lakes, ponds, reservoirs, wetlands, and other surface water features.



Buffer processing in the GIS was done step-wise, for each of the three NHD datasets plus the NWI, and then all four buffers were merged into a single data layer to be used in masking out areas of SDA that fall within the buffers. Note that actual surface water features (lakes, ponds, rivers) are not included in the buffer since they are undevelopable for water supply, and in most cases are not included in the SDA base data.

Hydrological buffers also affect large areas of the SDA in nearly every region of the state. The map inset to the right shows the same area depicted above for transportation buffers in the Rochester-Dover area with the hydrological buffers shown in blue and the remaining aquifer area shown in gray. It is worth noting that while transportation and other human features may change in extent and distribution over time as land development proceeds, the hydrological buffers can be expected to remain constant, or nearly so.

Known and Potential Contamination Sites

NHDES maintains a database of known and potential contamination sites statewide. In most cases, this is represented by a geographic point located where the site is known to exist (spill sites, leaking storage tanks, etc.), but some sites are large enough to be displayed as polygons (e.g., certain landfills, sewage lagoons, and junkyards).

The original FGWA project used eleven different datasets to aggregate all known and potential contamination sites for buffering[6]. Drawing on those datasets, this update uses a more detailed breakdown of ***project types (contamination sites)*** in order to make better use of the master attribute table and project status database provided by NHDES. A total of twenty-nine (29) types of features were thus systematically buffered. See ***Appendix C*** for a table of known and potential contamination sites, where the various acronyms are explained and the buffer distances used in this update of the FGWA are listed.

The datasets provided by NHDES for this project are as follows:

- Aboveground Storage Tank Facilities
- Asbestos Disposal Sites
- Automobile Salvage Yards
- Local Potential Contamination Source Inventory
- Local Protection Priorities
- National Pollutant Discharge Elimination System
- Point/Non-Point Potential Pollution Sources
- RCRA Hazardous Waste Generators
- Site Remediation and Groundwater Hazards Inventory
- Toxic Release Inventory (USEPA)
- Underground Storage Tank Facilities

Guidance in applying buffers was found in Tables 3-7 in the *Volume 2 GIS Operators Manual*. However, the list of contamination sites and types has been modified somewhat since the original modeling work in 1998. Pesticide application data are no longer used in the buffering, for example, due to the imprecision of actual area where pesticides are used. New project type categories such as Ether (including wells where the gasoline additive MtBE has been detected) and Formerly Used Defense Sites (FUDS) are included.

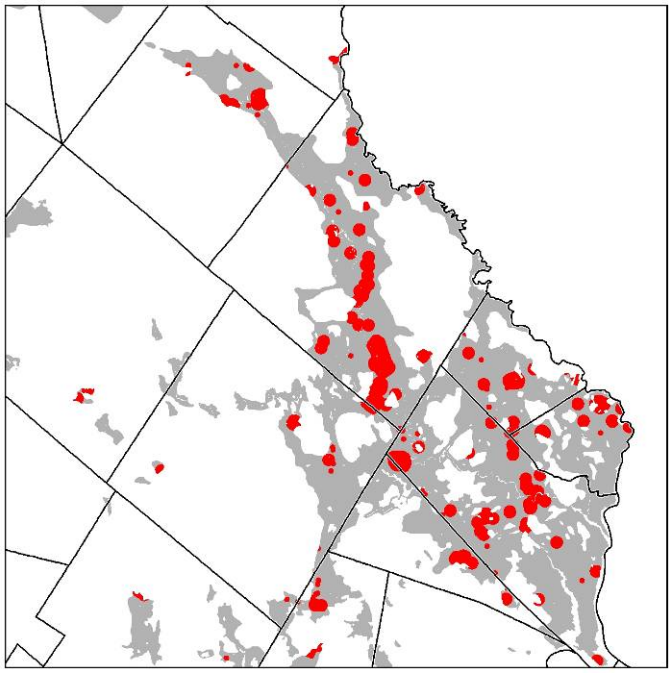
Note that these buffers do not vary as a function of well pumping rate. The SPR buffer distance of either 300 feet or 400 feet is applied, where appropriate, to cover the threshold pumping rate of 75 gpm (SPR 300), or greater than 150 gpm (SPR 400).

Again, this modeling effort is intended to be a first-cut analysis, not a guarantee of protection from water quality problems. There is not enough data accuracy in the aquifer transmissivity, saturated

[6] See Section 3.5 of the Vol 2 GIS Operators Manual, page 12

thickness and water table data to create situation-specific buffers; only detailed hydro-geological study can determine those parameters. Since groundwater flow gradient could not be incorporated, circular buffers had to be used. However, circular buffers encompass a significant amount of land that will not necessarily be affected by any contamination plume at the well site. On the other hand, hydrological models imply that, in specific circumstances, contamination can be drawn to a well across long distances. Therefore, 1,000 feet was chosen as an arbitrary buffer for sites of serious concern to balance a fully conservative approach which would constrain a large amount of excess land. Local entities, having site specific knowledge of contamination sites may choose to assign different buffers accordingly.

The NHDES GIS database query process must determine which contamination sites are currently active or not, using a special database file (*cst_projtype-lut.dbf*) provided by NHDES. This database contains a field for every project type, and identifies if a specific project identification code is active. See ***Appendix F*** for query language and further notes. All 29 active project types were appropriately buffered and then unioned into a single data layer for use in masking the SDA.



As with the other buffer regimes above, the map to the right shows the location of known and potential contamination buffers in the Rochester-Dover area in red. Note that there are many overlapping contamination source buffers, which in effect increases the degree of concern for certain areas in the aquifer. However, for the purposes of the FGWA analysis, only a dissolved data layer is used to mask out aquifer areas.

The data used in this FGWA update are current to the period June to December, 2009, depending upon the cycle of internal database updates at NHDES. As such, these data are a "snapshot in time", always being added to in places, but also deleting specific project sites once remediation is complete. While the data are generally available upon request to NHDES, some datasets are sensitive in nature and cannot be released without special approvals. Inquiries about security-sensitive data should be made at pierce.rigrod@des.nh.gov.

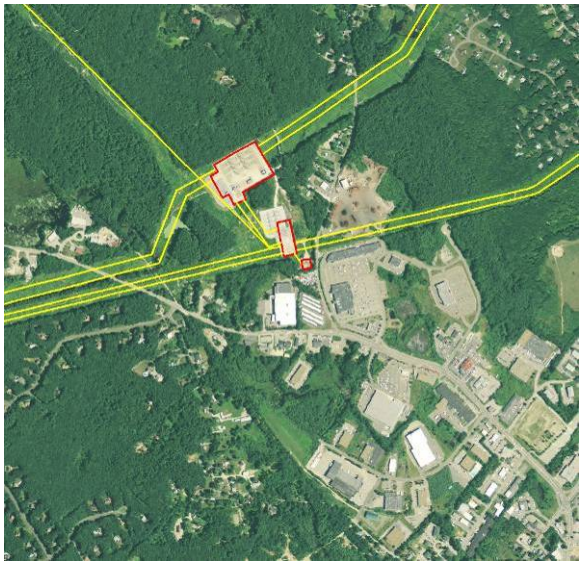
Other Urban Features

Two datasets available from GRANIT are useful in mapping certain other urban features that might impact high-yield SDA well sites. One locates all railroads, both active and inactive statewide. The other is named Pipelines, but actually contains transmission and telephone lines, power stations and substations, hydroelectric plants, airports, and a miscellaneous category. Both datasets were released in 1993, with no revisions posted on the GRANIT website, so it is possible that new

installations may exist in the utilities data. Only active railroads and non-water bearing pipelines are considered in this FGWA update.

Guidance in buffering these features was drawn from Table 3-6 in the *Volume 2 GIS Operators Manual*. As with the transportation right-of-way, current aerial photographs were measured to help determine a reasonable width of railroad and utility right-of-way as basis. Railroad right-of-way scaled at 50 feet, most often. Pipelines and telephone lines were found to be 75 feet typically around the state. Transmission lines vary in right-of-way width considerably, occasionally as little as 150 feet, but ranging up to about 500 feet in the larger corridors; a working median width was selected at 350 feet. Community planners using this model are encouraged to research and utilize actual right of way widths determined from tax records or aerial photo measurement.

The photo inset to the right shows several typical transmission line rights-of-way in an aerial photo in southern New Hampshire. The lines are shown in yellow, and a large substation in red.

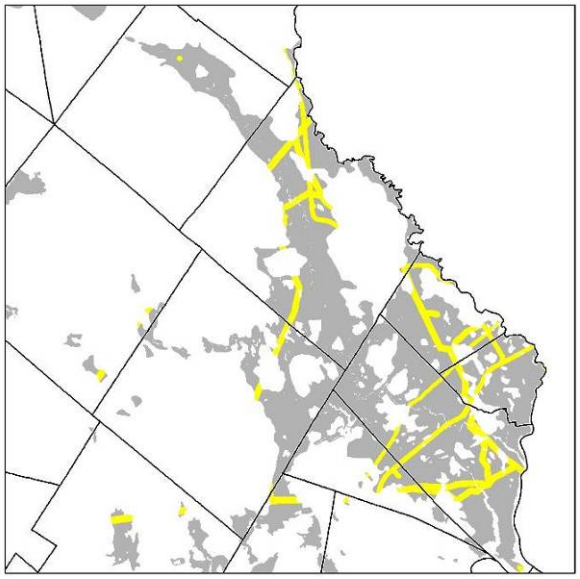


Like road rights-of-way, the rule is the SPR plus half the right-of-way width. **Table 2** below lists the urban features used in the model, and associated buffer distances. Railroads were buffered at 325' and 425', respective of SPR.

Table 2: Urban Feature Buffers

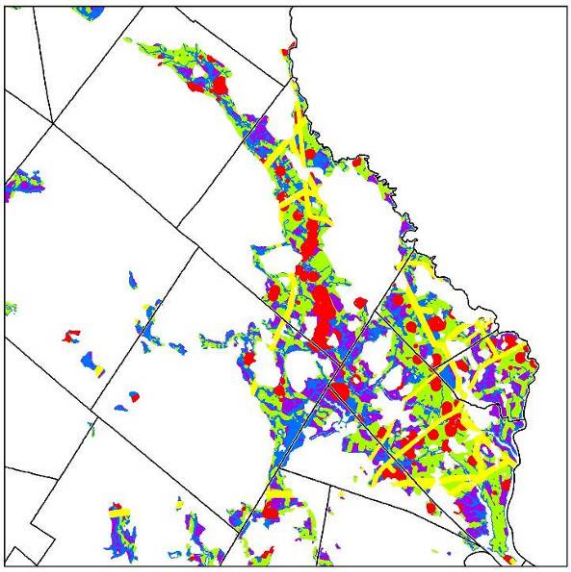
Urban Feature	SPR 300 Buffer	SPR 400 Buffer
Transmission Lines	475	575
Pipeline	338	438
Telephone Line	338	438
Power Station	300	400
Substation	300	400
Hydro Plant	300	400
Airport	300	400
Other	300	400

The map to the right shows the effect of urban features buffers on the Rochester-Dover area. The yellow areas show where transmission lines, pipelines, and railroads cross the aquifer area.



For more discussion of additional urban features that could be incorporated into this system of buffers, see ***Section 4: FGWA Data Trends 2002 to 2010*** and ***Section 5: Recommendations for Further Enhancement.***

Each buffer regime data layer reveals its own patterns and varies in terms of extent of impact on the aquifer areas, but it is in overlaying all the buffers that the effects of hydrological and various human land uses becomes apparent in the mapping, and ultimately in the statistical analysis of how much favorable gravel well siting area currently remains.



The Rochester-Dover area is a good example of the pressure urbanization has had, and likely will continue to have, on high-yield SDA groundwater resources in growth regions of the state. The map to the left shows a composite of all four buffers using the color schemes in the preceding vignettes. The gray background color of the aquifer basin here is changed to purple to highlight the remaining land area potentially suitable for municipal well development.

Note two things: the relatively small fraction of overall and area left for well development after buffering, and the scattered nature of the geographic distribution of these areas.

This kind of congestion and fragmentation is not typical of aquifer basins in more rural locations in New Hampshire, but in the southeastern quarter of the state, it represents the status quo.

Section 3: RESULTS OF THE UPDATED MODEL

Overview

The results of the multiple buffer exercise are discussed below. First it is important to understand the varying potential well yield inherent in the transmissivity of the SDA formations. The entire concept of transmissivity and well yield is explained in detail in ***Appendix D***. Using the transmissivity coding of the aquifer mapping, it is possible to construct a set of yield classes keyed to the 75 gpm and 150 gpm well pumping rate targets set by NHDES for this study. **Table 3** below lists the potential yield for each of the transmissivity ranges in the aquifer mapping. Note that the ranges for T-minimum (T-min) and T-maximum (T max) are not consistent statewide across the several aquifer studies, but the yields have been carefully calculated in Table 1 of Appendix D.

Table 3: Potential Well Yield Class by Transmissivity

Transmissivity		Yield Class
T min	***T max***	
0	500	< 75 gpm
0	1000	< 75 gpm
0	2000	>=75 gpm but <150 gpm
1000	2000	>=75 gpm but <150 gpm
2000	2000	150 gpm
2000	4000	>=150 gpm but <300 gpm
3000	99999	>=150 gpm but upper limit unknown
4000	99999	>=150 gpm but upper limit unknown
4000	8000	>=300 gpm
8000	99999	>=300 gpm

By detailing potential well yields according to yield class in the mapping and the statistics, the extent and distribution of remaining potential well site lands become more apparent, and priorities for protection of these remaining drinking water resources can be set geographically, and strategically. Well sites with potential yields greater than 300 gpm are rare in the state, but are highlighted in this classification system to help identify very high-yield aquifer areas.

At its most general level, the aquifer land area remaining after buffering all roads, hydrological features, contamination sites, and urban features can be viewed in proportion to the entire SDA "footprint" statewide and by aquifer basin. The total acreage of SDA under consideration in the FGWA model is 805, 550 acres[7]. After buffering, the FGWA model yields two numbers to compare: the SPR 300 tallies for well sites capable of pumping at least 75 gpm, and SPR 400 calculations for wells greater than or equal to 150 gpm. ***The SDA land area remaining after subtracting 300-foot buffers totals 246,066 acres, or 30.5% of all SDA surface area***. The land

[7] This represents the total mapped stratified-drift area of all thirteen aquifer study areas, exclusive of areas mapped as non-transmissive formations, such as till, bedrock, or estuarine and lacustrine deposits without underlying sand and gravel.

area remaining using 400-foot buffer distances, which are more restrictive, ***totals 208,912 acres, or nearly 26% of all SDA area***.

Note, then, that of all the total SDA area statewide, only about one-quarter to one-third of that area currently remains for any development of new municipal water wells. However, the actual areas with sufficient yield for wells of at least 75 gpm or greater are a fraction of this gross fraction (see last line in Table 4 below).

Table 4 below lists the yield classes explained earlier according to likely pumping rates within the remaining SDA areas, and summarizes the actual acreage associated with each yield class. The table requires interpretation here:

- First, note the <75 gpm yield class; these are areas where the aquifer mapping indicates insufficient transmissivity to support high-yield well sites.
- Second, the SPR 300 portion of the table lists all yield classes and SPR 300 areas across the entire remaining aquifer, but for the 75 gpm high-yield well target,
- Third, the corresponding SPR 400 portion of the table pertains to very high-yield well sites with potential for 150 gpm or more. In this case, the lower two yield classes are not relevant, but are included for context.
- Fourth, the aquifer mapping in some basins contains areas of unknown transmissivity due to insufficient data at the time of the mapping. These areas are classed "undefined," and may or may not contain areas suitable for well development.

Table 4: 2010 SDA Remaining After Buffering by Yield Class and Target Pumping Rate

	SPR 300 (>=75 gpm)		SPR 400 (>=150 gpm)	
Yield Class	**Acres**	**Percent of Total Area**	**Acres**	**Percent of Total Area**
<75 gpm	130,324.1	53.0%	110,537.9	52.9%
>=75 gpm but <150 gpm	55,176.4	22.4%	45,135.9	21.6%
150 gpm	2,896.8	1.2%	2,414.5	1.2%
>=150 gpm but <300 gpm	15,664.2	6.4%	13,357.4	6.4%
>=150 gpm but upper limit unknown	50.5	0.0%	38.0	0.0%
>=300 gpm	10,787.9	4.4%	9,146.1	4.4%
Undefined	31,166.7	12.7%	28,282.8	13.5%
Total area outside buffers	**246,066.6**		**208,912.6**	
Total area outside buffers with sufficient yield	**84,575.8**	34.3%	**24.956.0**	11.9%

Note: The green-shaded areas of the table represent aquifer areas with adequate transmissivity for high-yield (>=75 gpm) and very-high_yield (>=150 gpm) wells.

Several important points about the scarcity of potential well sites become apparent in looking at **Table 4**. First, a very large portion of the land area remaining outside the buffers is not suitable for wells of 75 gpm or higher. In the SPR 300 category, 53% of the area does not meet the transmissivity requirements, and another 12.7% falls in the undefined yield class, or in other words, ***two-thirds of the SPR 300 area is not or may not be suitable for municipal well development.*** The situation is even more extreme in the SPR 400 category, where 88% of the land area is not or may not be suitable for wells pumping 150 gpm or more, or in other words, ***only about 12% of the SDA left remaining after buffering is suitable for municipal well development at that pumping rate***.

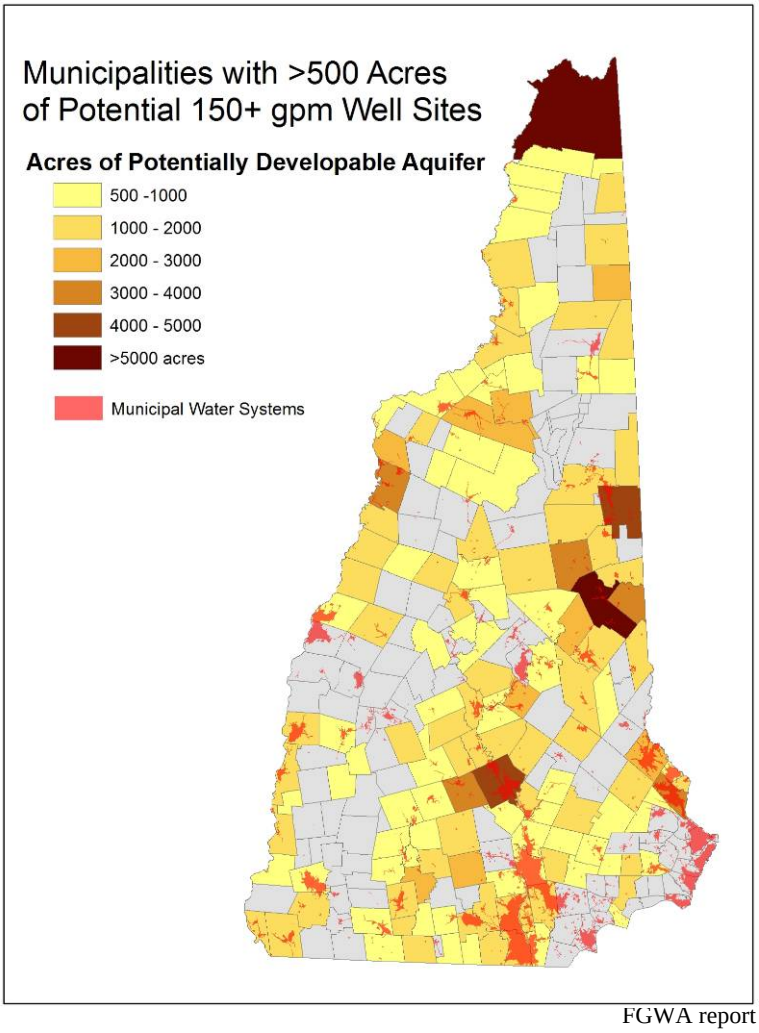
Geographic Distribution

It is important to note that while the statistical summary above indicates a situation of scarcity in terms of the relatively limited land area for municipal well development, many of the higher yielding formations are not located in proximity to communities in the state with higher population densities and/or existing public water supply systems. The following discussion and mapping refers to the ***unconstrained high-yield or very high-yield aquifer areas*** outside any buffered land area.

The map at the right displays municipalities with high-yield SDA containing potential well sites of 150 gpm or greater. Communities with darker colors indicate extensive areas of high-yielding aquifer formations.

Those areas served by public water systems are highlighted in red. Note that not all public water systems are dependent upon groundwater supplies; rivers and surface water reservoirs play important roles in Manchester, Concord, and 38 other New Hampshire communities.

However, several rural areas with abundant groundwater resources appear on the map, including Pittsburg in the far north, and the Ossipee region with Tamworth and Effingham sharing the natural resource wealth with Ossipee. Nearby Conway also stands out, as does Hopkinton just west of Concord. Haverhill in the upper Connecticut River valley is also highlighted.



Pittsburg can be considered an anomaly in this map; not only is it the furthest removed of any New Hampshire community from the more populated southern municipalities, but its large land area contributes to its top ranking in this display. On the other hand, the City of Concord, with more than 650 persons per square mile, cannot be considered rural, but it does boast 4,400 acres of high-yield aquifer formation with potential for future public well sites.

Looking at the aquifer study areas in terms of relative abundance of favorable gravel well sites remaining provides a similar perspective. **Table 5** below lists the thirteen aquifer study areas with a summary of the stratified-drift aquifer acreage remaining after removing the SPR 300 and SPR 400 buffers. While some study areas have rather large total aquifer areas, several of them show low percentages of SDA area remaining outside the buffers, including the Lower Merrimack, the Nashua, the Middle Merrimack, and the Cocheco study areas, all of which have seen decades of population growth and conversion of natural aquifer land area to human uses.

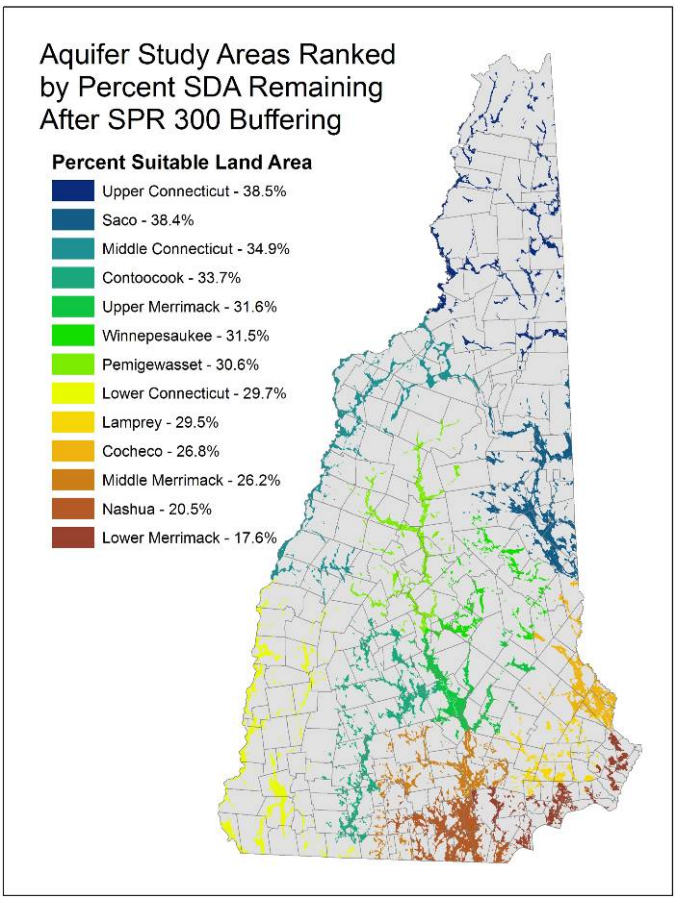
Note that the SDA acreages under the SPR 400 portion of the table represent even lower percentages of basin area, and those basins with the higher percentages of basin remaining outside buffers are furthest from the more populated communities in southeast New Hampshire.

Table 5: Summary of Stratified-Drift Aquifer Area Outside Buffers by Aquifer Study Area

Aquifer Study Area	Total SDA Acres	SPR 300 Acres	Percent Aquifer Area	SPR 400 Acres	Percent Aquifer Area
Cocheco	49,182	13,190	26.8%	11,042	22.5%
Contoocook	77,791	26,188	33.7%	22,648	29.1%
Lamprey	32,794	9,679	29.5%	8,030	24.5%
Lower Connecticut	71,166	21,150	29.7%	17,251	24.2%
Lower Merrimack	48,809	8,584	17.6%	6,587	13.5%
Middle Connecticut	79,117	27,587	34.9%	23,581	29.8%
Middle Merrimack	57,439	15,067	26.2%	12,525	21.8%
Nashua	79,714	16,367	20.5%	13,024	16.3%
Pemigewasset	56,109	17,143	30.6%	13,993	24.9%
Saco	87,449	33,599	38.4%	29,299	33.5%
Upper Connecticut	73,834	28,425	38.5%	25,974	35.2%
Upper Merrimack	52,264	16,540	31.6%	14,121	27.0%
Winnipesaukee	39,882	12,547	31.5%	10,837	27.2%
Total area	**805,551**				
Total area outside buffers		**246,066**	**30.5%**	**208,912**	**25.9%**

The map at the right displays the thirteen aquifer study areas ranked and color-coded according to the percentage of SDA area in each study area that remains after removing SPR 300 buffers.

Note how those study areas with the greatest potential for well development are located in the northern half of the state, while the study areas in southeastern New Hampshire show the smallest reserve capacity in terms of available aquifer area.



Scanning the patterns in both maps, it should be clear that the high-yield aquifer resource is scattered extensively around the state, and it is not convenient to the rapidly urbanizing community centers in the southeastern quarter of the state. This raises an interesting question as to whether the yet untapped groundwater resources will benefit the growth areas of the state over distance, or will the population growth follow the availability of water resources that can support that growth as well as economic development? In either case, stewardship of the remaining groundwater resource will be key.

Protection Status

By overlaying the GRANIT *Conservation and Public Lands* data layer on the two versions of the FGWA results, the status of potential water supply lands can be determined at statewide scale, as well as by aquifer study area and by municipality. Each perspective is highlighted below.

Statewide Summary

Table 6 below summarizes the number of acres and percent protection for the SPR 300 and SPR 400 aquifer areas statewide[8]. Note that taken as a whole, the aquifer area remaining for potential well development (although not necessarily for large municipal wells, since the numbers in Table 6 include SDA areas with insufficient yield) is only about 22% to 24% protected, depending on the well siting buffers (300 or 400 ft). The table further breaks down aquifer area and land protection.

Under the SPR 300 portion of the table, note that the yield class that equates to a pumping rate target of at least 75 gpm but less than 150 gpm is only about 18% protected, yet the 55,000+ acres of land in that class amounts to about two-thirds of all the aquifer area with potential for municipal well sites (~84,500 acres). This disparity points up the need for significant protection of this particular groundwater resource.

The SPR 400 side of the table shows relatively higher percentages of land protection by yield class, but the total aquifer area suitable for these high-yield wells is only 25,000 acres, with a little more

[8] Based on GRANIT Conservation & Public Lands data released 2/2009.

than 26% of that land currently protected. Note that in the two yield classes with the greatest land area (>=150 gpm but <300 gpm, and >=300 gpm), the protection status is only about 25%, which indicates a need to give priority to these scattered and scarce aquifer areas for future well development.

Table 6: Protection Status by Yield Class for FGWA 2010

	SPR 300			SPR 400		
Yield Class	**Acres**	**Acres Protected**	**Percent Protected**	**Acres**	**Acres Protected**	**Percent Protected**
<75 gpm	130,324.1	**25,169.2**	**19.3%**	110,537.9	**22,748.1**	**20.6%**
>=75 gpm but <150 gpm	55,176.4	**9,992.3**	**18.1%**	45,135.9	**8,951.4**	**19.8%**
150 gpm	2,896.8	**1,129.2**	**39.0%**	2,414.5	**991.4**	**41.1%**
>=150 gpm but <300 gpm	15,664.2	**3,756.6**	**24.0%**	13,357.4	**3,418.0**	**25.6%**
>=150 gpm but upper limit unknown	50.5	**13.7**	**27.1%**	38.0	**12.2**	**32.1%**
>=300 gpm	10,787.9	**2,411.9**	**22.4%**	9,146.1	**2,186.8**	**23.9%**
Undefined	31,166.7	**11,783.5**	**37.8%**	28,282.8	**10,930.2**	**38.6%**
Total All Yield Classes	**246,066.6**	**54,256.4**	**22.0%**	**208,912.6**	**49,238.1**	**23.6%**
Total FGWA 300 or FGWA 400	**84,575.8**	**17,307.8**	**20.5%**	**24,956.0**	**6,609.8**	**26.6%**

Note: The green-shaded areas of the table represent aquifer areas with adequate transmissivity for high-yield (FGWA 300) and very high_yield (FGWA 400) wells.

Regional Summary

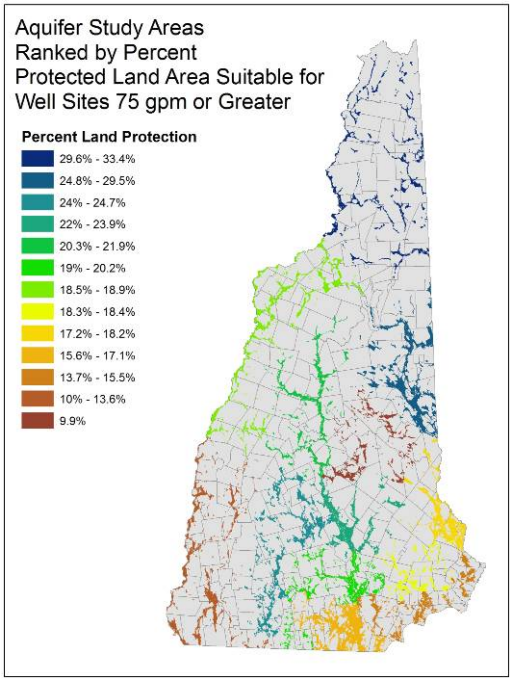
Protection status by aquifer study area is an important way to look at available groundwater resources since it spans the entire natural system that the SDA represents, and helps the communities that share a given aquifer study area (river basins in most cases) better understand their mutual stewardship responsibilities. The data also provide a somewhat different perspective in terms of priority for protecting key water supply lands compared to the discussion above of scarcity of suitable land area by basin.

Table 7 below lists New Hampshire's aquifer study areas ranked by the percent of land, remaining after buffering for SPR 300, that is currently protected from encroaching land uses. Note the very low levels of protection for the Winnipesaukee study area, as well as the relatively low percentages for the Lower Merrimack and Lower Connecticut. The land use character of these three basins varies considerably from rural to more built-up. However, the pressure of continuing urban development over time in the southeast does not appear to be a key factor in explaining why more critical groundwater resource lands are not protected. The Cocheco and Lamprey basins on the Seacoast have seen significant land use change in the last couple of decades, but are twice as protected as the Winnipesaukee basin, percent-wise.

Table 7: Aquifer Study Areas by Percent of SPR 300[9] Acres Protected in 2010

Aquifer Study Area	Total SDA Acres	SPR 300 Acres	SPR 300 Acres Protected	Percent Protected
Upper Connecticut	73,834	28,425	9,506	33.4%
Saco	87,449	33,599	9,903	29.5%
Contoocook	77,791	26,188	6,478	24.7%
Upper Merrimack	52,264	16,540	3,953	23.9%
Pemigewasset	56,109	17,143	3,756	21.9%
Middle Merrimack	57,439	15,067	3,038	20.2%
Middle Connecticut	79,117	27,587	5,202	18.9%
Lamprey	32,794	9,679	1,784	18.4%
Cocheco	49,182	13,190	2,403	18.2%
Nashua	79,714	16,367	2,795	17.1%
Lower Merrimack	48,809	8,584	1,330	15.5%
Lower Connecticut	71,166	21,150	2,867	13.6%
Winnipesaukee	39,882	12,547	1,243	9.9%
	805,551	**246,066**	**54,257**	**22.0%**

The map to the right displays the thirteen aquifer study areas ranked by percent of SPR 300 land area protected. Note how the Winnipesaukee basin is well north of the urban corridor along the Merrimack River, and the Lower Connecticut basin occupies the southwest corner of the state which has not seen the kind of population growth and land use change as the southeastern quarter of the state.



On the good news side, the Upper Connecticut and Saco basins have the highest levels of SPR 300 land protection, thanks in part to the White Mountain National Forest and other large conservation and public land reserves in the North Country. The extensive Contoocook basin which coincides with the most recent land development "frontier" west of the City of Concord in mid-state holds third place in the rankings statewide.

Generally, the southeast shows a cluster of relatively low levels of land protection, and collectively might warrant priority in light of population pressures and growing need for future water supplies.

Municipal Summary

[9] "SDA 300" is the gross land area of SDA remaining after removing areas that are unfavorable due to quality reasons by applying a 300-foot buffer as required for wells with 75 gpm or greater pumping rates.

Parsing out the 2010 FGWA data by municipality is the third and final perspective generated in this study. Looking at the groundwater resource at community scale is critical because in most cases it is the local community that benefits from the water supply opportunity, either presently or in planning for the future.

Table 8 below lists the top 25 municipalities[10] ranked by total acres of SPR 300 land area, along with the status of land protection for that groundwater resource. The SPR 300 area for these communities totals nearly 80,000 acres, or about one-third of all SPR 300 land statewide. Communities with abundant SPR 300 area, but low in percent of resource protection, are flagged in bold type in the list.

Table 8: Communities with SPR 300 Aquifer Area in 2010

Municipality	Total SPR 300 Acres	Acres Protected	Percent Protected
Ossipee	6,482.2	1,396.4	21.5%
Pittsburg	5,734.2	4,162.7	72.6%
Conway	**5,207.9**	**707.3**	**13.6%**
Concord	5,189.7	1,525.5	29.4%
Hopkinton	4,312.9	1,013.1	23.5%
Tamworth	3,999.6	1,414.6	35.4%
Effingham	3,689.7	1,364.6	37.0%
Dover	3,671.4	1,101.5	30.0%
Haverhill	3,566.3	729.3	20.5%
Bethlehem	3,092.6	1,528.8	49.4%
Belmont	**2,975.1**	**271.5**	**9.1%**
Cambridge	**2,844.5**	**229.4**	**8.1%**
Bath	**2,811.1**	**130.9**	**4.7%**
Carroll	2,724.8	678.6	24.9%
Rochester	**2,551.4**	**220.2**	**8.6%**
New Boston	2,502.1	1,001.4	40.0%
Tuftonboro	**2,419.7**	**64.0**	**2.6%**
Hollis	2,370.8	629.9	26.6%
Litchfield	**2,330.1**	**329.1**	**14.1%**
Freedom	2,283.5	963.4	42.2%
Madison	2,233.3	749.1	33.5%
Albany	2,204.5	1,576.8	71.5%
Greenfield	2,149.1	462.3	21.5%
Walpole	2,146.0	729.2	34.0%

Of these towns, the majority currently show more than 20% resource protection, which may be a reasonable threshold value if the land protected coincides with the higher yield classes in the FGWA. Several communities stand out with relatively low levels of resource protection, as low as 2.6% in Tuftonboro, but only about 14% in Conway, with more than 5,200 acres of SPR 300 land, and 8.6% in Rochester, with about 2,600 acres.

[10] The choice of (25) represents approximately the top 10% of the 234 municipalities in N.H.

While many of the communities in the list are very rural, with little demand likely on groundwater supplies in the foreseeable future, places like Conway, Rochester and Litchfield are growth areas where water demand will almost certainly increase. Note also, the importance of the several towns on the Saco basin aquifer – Ossipee, Tamworth, Effingham, Tuftonboro, Freedom, and Madison – an extensive cluster of groundwater-rich communities not matched elsewhere in the state in terms of future water supply development.

A different picture of source water protection emerges in **Table 9** on the next page. Again, the top 25 municipalities in New Hampshire are listed, but in this table they are ranked according to the extent of SDA suitable for high-yield wells pumping 75 gpm or greater according to transmissivity yield classes discussed earlier. In comparing Tables 8 and 9, note where communities appear in both tables, how the acreage totals in the FGWA 300 are significantly less than the gross SPR 300 land areas.

Note also that while some municipalities have relatively high levels of protection on FGWA 300 and 400 land, others are quite low. More than half the communities listed have FGWA 300 land protection levels of less than 15%, and nine are rated at less than 10%. While some municipalities with relatively low levels of critical aquifer protection are quite rural, e.g., Rumney, Thornton or Bartlett, others such as Rochester, Merrimack, Amherst, Plymouth, Hudson and Brookline, are much more urbanized and have higher populations dependent upon public water supplies drawn from stratified-drift aquifers.

One final point is apparent when looking at the FGWA 400 side of Table 9: the aquifer land area suitable for very high-yield wells pumping 150 gpm or greater is significantly less than the FGWA 300 data, and the level of protection on these key aquifer areas varies widely, topping 50% in five communities, but currently at less than 15% in twelve municipalities.

As the numbers in the preceding tables telescope down from total area of stratified-drift aquifer to the area remaining after buffering for water quality impacts, and then to the actual land area suitable for municipal well development based on yield, the relative scarcity of this critical natural resource should be apparent. With the very finite nature of the resource in mind, the question also emerges as to how much of this land should be permanently protected to ensure future water quality and quantity.

Table 9: Communities with FGWA 300 and 400 Aquifer Area in 2010

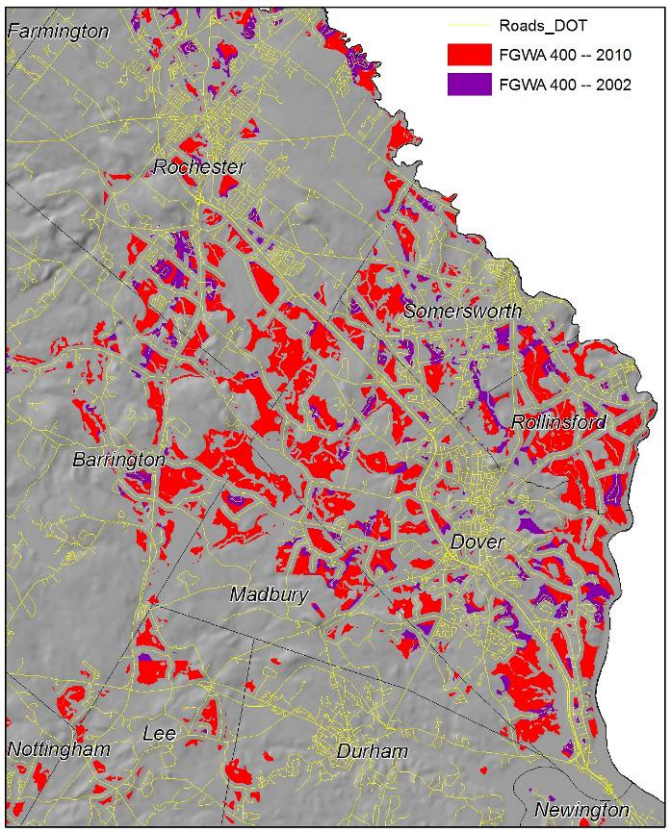
	FGWA 300			FGWA 400		
	High-Yield Wells (>75 gpm)			Very High-Yield Wells (>150 gpm)		
Municipality	Total Acres Suitable	Total Acres Protected	Percent Protected	Total Acres Suitable	Total Acres Protected	Percent Protected
Ossipee	3,798	1,223	32.2%	1,578	525	33.3%
Dover	3,630	1,101	30.3%	84	54	63.8%
Rochester	2,551	220	8.6%	220	43	19.5%
Hollis	2,371	630	26.6%	880	369	41.9%
Litchfield	2,330	329	14.1%	209	17	8.1%
Conway	2,277	307	13.5%	1,776	261	14.7%
Tamworth	2,050	611	29.8%	1,121	357	31.8%
Merrimack	1,992	270	13.5%	249	52	20.7%
Milford	1,865	295	15.8%	562	182	32.4%
Rumney	1,708	9	0.5%	266	0	0.0%
Amherst	1,618	108	6.7%	793	47	5.9%
Thornton	1,598	94	5.9%	651	14	2.2%
Barrington	1,598	169	10.5%	25	0	1.5%
Nashua	1,549	484	31.2%	668	384	57.4%
Effingham	1,528	478	31.3%	211	33	15.6%
Sanbornton	1,447	271	18.7%	1,247	231	18.5%
Plymouth	1,445	32	2.2%	9	0	0.0%
Swanzey	1,356	51	3.8%	751	37	4.9%
Rollinsford	1,337	248	18.5%	0	0	0.0%
Bartlett	1,324	105	7.9%	841	43	5.1%
Madison	1,210	432	35.7%	713	364	51.1%
Wilton	1,207	299	24.8%	97	62	64.2%
Hudson	1,199	103	8.6%	33	1	3.1%
Brookline	1,166	87	7.5%	426	59	13.8%
Freedom	1,088	377	34.7%	415	255	61.5%

Section 4: FGWA DATA TRENDS 2002 to 2010

It is not possible to generate a one-to-one comparison of the status of FGWA 300 and 400 lands from 2002 to 2010 due to the differences in the data sources used to create the buffers of various features, although that would be ideal over time. Even comparing the total land area for each FGWA dataset for the two time periods is not meaningful. However, with the new NHDOT and National Hydrography (NHD) data now available as standard baseline, and the consistency over time in the NHDES contamination sites data, it may be reasonable to update the FGWA in five years to extract precise land use change data.

Nevertheless, two analyses were conducted for this study as part of the accuracy check process in building the new data layer, both of which made it possible to calculate land area changes due to road buffers and due to changes in the contaminations site data.

New Roads & Ancillary Development



The map to the left depicts the Cocheco aquifer study area in the Route 16 corridor between Dover and Rochester. The 2002 FGWA 400 dataset for well sites yielding 150 gpm or greater is shown in purple; the 2010 data are shown overlaid in red. The NHDOT roads and highway network appears in yellow.

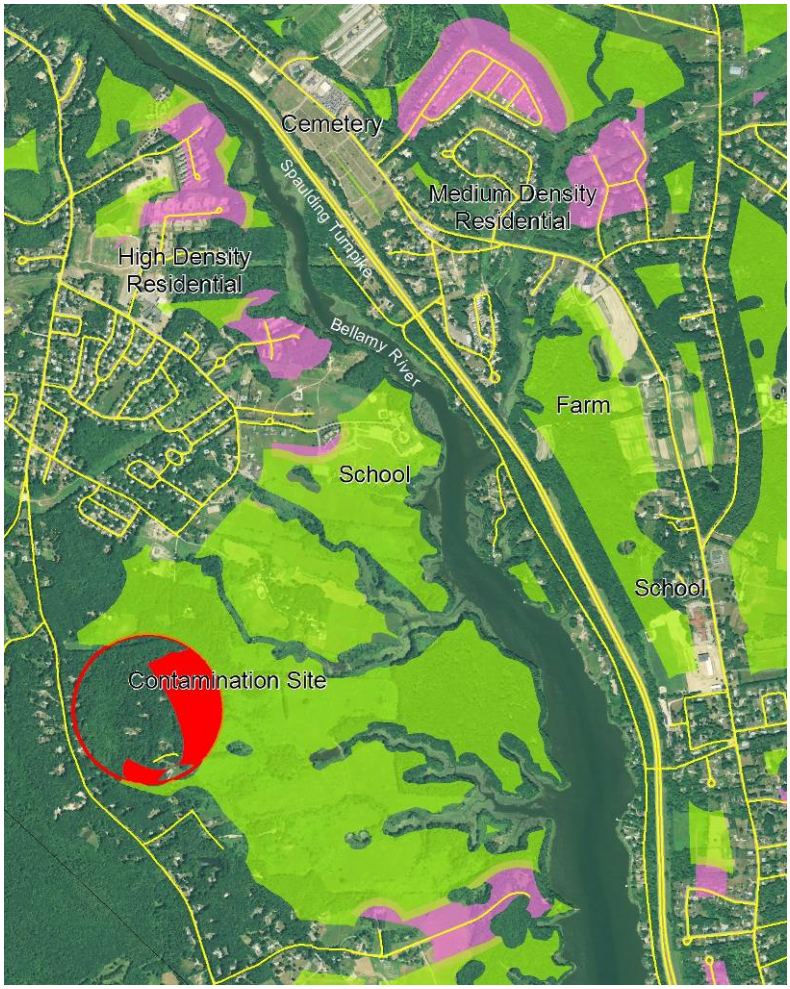
Note the many areas in which new roads and associated development buffers encroach on the 2002 FGWA 400. Using this method, ***a total of 19,600 acres of the 2002 dataset appears to have been lost to new development statewide, or about 9% of available 150-gpm potential well sites in eight years.***

This may be an overstatement in terms of the time period because some recent roads and ancillary development may have been in place in 2002, but were not incorporated into the NHDOT data used at the time (in conjunction with the USGS roads data in the previous protocol). On the other hand, updating the NHDOT data will always show a lag time between construction and documentation spatially, so even the most recent data will be incomplete.

The aerial photo map shown below gives a better sense of the types of land use change picked up by comparing the current NHDOT data with the 2002 FGWA. The image centers in Dover near Great

Bay, with the Bellamy River and the Spaulding Turnpike (Route 16) appearing diagonally across the photo.

The green areas represent the new 2010 FGWA 300 data layer developed in this study which holds potential for municipal wells of 75 gpm or more. Shown in pink are areas that were previously part of the 2002 FGWA 300 mapping, and are now developed. Note that in this snapshot all the encroachment areas have been converted to residential land uses of varying density, typical of the patterns of land development in this rapidly urbanizing region.



Looking more closely at the green areas, one can see various other land uses that are not picked up in the methodology used in this update. Near the center of the photo is a large school facility, and across the river is a farm with fields overlapping into the FGWA 300 (although farm land would not be likely to prevent well development in the vicinity). Another school is expanding into the FGWA 300 on the right side of the photo near the Spaulding Turnpike. Other land uses that could affect well siting options also appear in these aerial photos, but are not recognized in the FGWA buffer methodology, including a cemetery near the top.

The large red circle in the lower left of the photo represents a contamination site currently in the NHDES database. The impact of this new data point upon the 2002 FGWA 300 appears as solid red. This marginal effect is typical of most contamination sites used in the update. Because the NHDES database is dynamic and constantly changing as sites are remediated or new sites are documented, it is not possible to calculate a trend between the two FGWA datasets. ***However, summing up the area for all the encroachment on the 2002 FGWA 300 by contamination sites, only 325 additional acres of 2002 FGWA 300 are lost in the 2010 analysis.***

One anomaly appears at the bottom of the photo. There is a road buffer across the aquifer to a single residence located on the river. This buffer was generated because the methodology includes all private roads that are digitized into the NHDOT data. In this case, the road serves as a driveway,

not a privately maintained road within a subdivision, which would be of concern in calculating available aquifer area for new well sites.

Thus, there is a scaling issue with the road buffer approach that needs to be addressed, and probably can only be addressed by using aerial photography of sufficient resolution and scale to allow refinements to be made after a first cut is made using the current protocol. While this suggestion is not practical at state or large regional scales, it is certainly within the scope of community resource inventories and planning studies.

Tracking Urbanization

As part of this study and update of the NHDES FGWA data, several ancillary data sources were reviewed and evaluated for potential incorporation into the statewide model, and/or for use by community planners to increase the accuracy of the FGWA assessment at municipal scale. The three datasets include:

- USGS National Land Cover Dataset (NLCD)
- CICEET[11] Land Use Change data for Strafford and Rockingham Counties
- Nashua Regional Planning Commission land use data by tax parcel

Each of these datasets has limitations for use, as discussed below, but in the process of assessing the accuracy of the FGWA data developed for this study, the use of NAIP[12] aerial photography in the GIS proved to be a valuable check against missed land use developments not signaled in the NHDOT roads and highway data, as well as a source of information about land uses that might be of concern at community scale when delineating favorable well site lands.

USGS NLCD

The NLCD was last updated in 2006 with special protocols used to increase accuracy for change detection since the original release of the data in 1996. Because it contains more recent land cover type mapping than the most current similar dataset at GRANIT, the NLCD was given precedence in this study for evaluation.

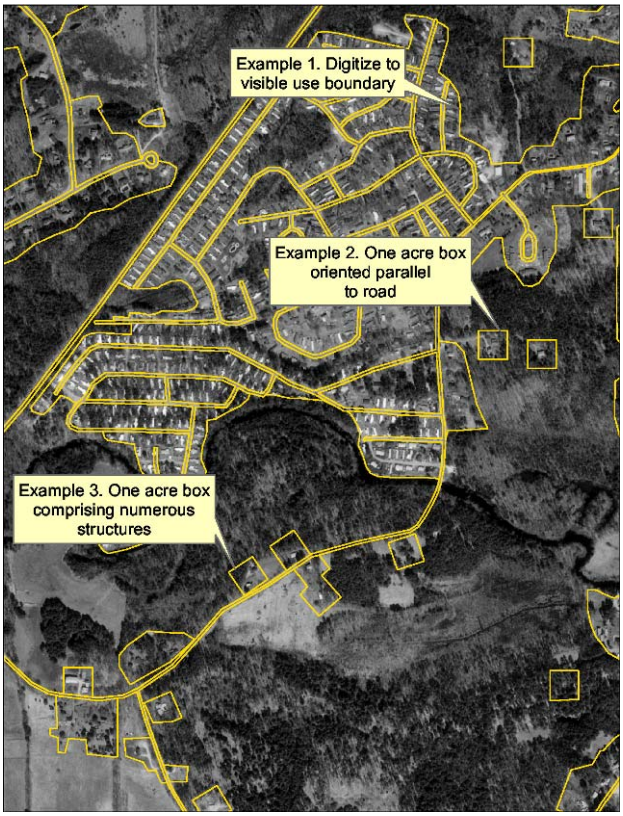
While the ability to track changes over time is important to projects such as the update of the FGWA, there are issues with the level of detail that can be displayed and the usefulness of the data at community scale. The resolution of the data is based on a 30-meter grid in raster format (about 1/5th of an acre per grid cell), and the overall accuracy of the grid data in terms of land use classification is about 85%. This means the depiction of land uses is somewhat coarse and without precise boundaries that are useful in buffering the aquifer formations.

[11] CICEET stands for the Cooperative Institute for Coastal & Estuarine Environmental Technology at UNH.
[12] National Agricultural Inventory Program, 1- or 2-meter color aerial photography typically issued each year and available from GRANIT

However, comparing the NLCD land classes for transportation and various urban land uses to the updated FGWA data generated using the buffer method discussed earlier in this report, it appears that the NHDOT roads and highways data, with associated buffers, serve as a highly accurate proxy for the land uses of concern along the highway network. In some cases, the NHDOT road patterns were more up-to-date than the NLCD transportation land use classes.

CICEET land use data

This dataset contains 13 categories of land use polygons for Rockingham and Strafford counties, and is based on a time series of data collected and digitized for 1962, 1974 and 1998. The purpose of the project was to analyze past and current land development trends and their impact on water quality in the coastal region. The primary source data for the study was 1:12,000 scale aerial photography for the three time periods. Digitization was conducted very carefully, and to the extent possible actual boundaries of a particular land use were digitized. In other cases, where boundaries were indistinct, a common unit of land size was incorporated. For example, low-density residential land uses which were given a minimum 0.5- or 1-acre polygon, depending upon sewer availability, to allow for accessory uses. Thus, the land use data displayed are very accurate and detailed.



The photograph to the left is taken from the CICEET study land use mapping standards manual which accompanies the GIS data. Note the detail, and the two forms of land use boundary mapping, edge of visible use and one-acre box land use proxy.

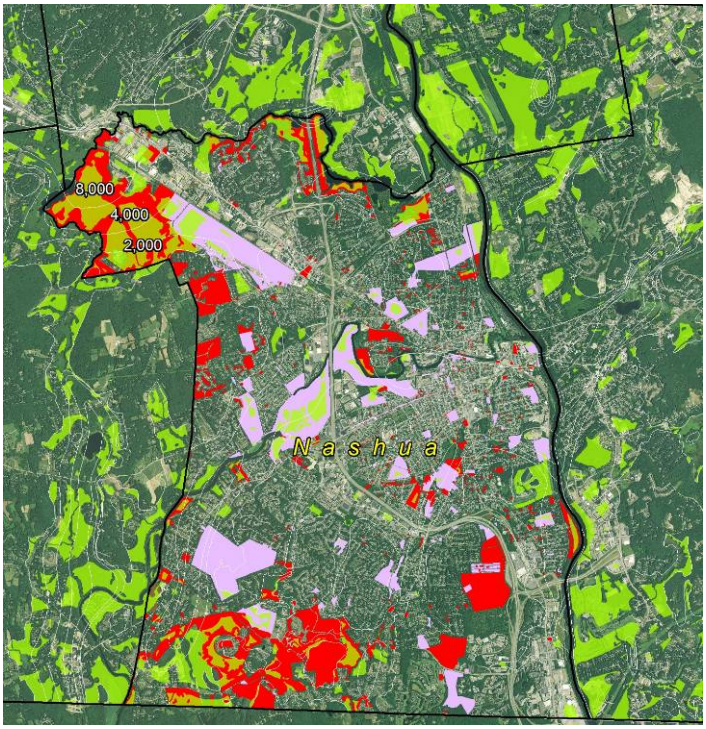
Comparison of the CICEET mapping to the NLCD land cover type mapping, and the new FGWA spatial data, shows a high degree of consistency. Unfortunately, the most recent land use data is 1998 and a great deal of land use change has occurred on aquifer basins in the two-county study area since then.

Perhaps the most important finding in testing this dataset is that it sets a standard for a similar, statewide land use mapping effort which would be invaluable to natural resource studies such as the NHDES FGWA project. In the meantime, reliance on the NHDOT transportation data *and the use of the ample buffers along highways and roadways* is a workable proxy for land use mapping in areas of higher density residential land uses and mixed land uses, which would be improved by comparison with aerial photography as seen in the previous photo. One caveat is also evident in the photo, however. Note scattered residential land uses in the lower third of the image; buffering the entire road does not reflect whether the land is vacant or developed, and in certain places, economically attractive prime well sites could exist on

such lightly settled roadways. This points to the need for detailed FGWA modeling and mapping at community scale to be sure all options are identified and evaluated.

Nashua Regional Planning Commission land use mapping

The Nashua Regional Planning Commission has a service area comprised of 12 towns and the City of Nashua. Ten years ago, the planning staff at the commission began a process of assembling parcel-based land use information for all towns with the goal of a seamless dataset across the service area. The list of land uses coded into this dataset is extensive, but two or three land use types are important here: vacant land, open land, and municipal land.



The photo to the left shows an aerial photo of the City of Nashua with parcels of vacant land class in red and municipal land in pink. The FGWA land suitable for development of wells pumping 75 gpm or more is shown in green, or yellowish green where it overlays the red.

Note the area of northwest Nashua with the large red vacant parcels. This land sits on a portion of the stratified-drift aquifer under Pennichuck Pond and the large wetland surrounding it. Minimum transmissivity values shown of 2,000 to 8,000 square feet per day indicate that this is a very high-yield aquifer zone.

While this area is currently utilized in part for municipal water supply, and it is permanently protected, the photo demonstrates the value to short- and long-range community planning of correlating FGWA data and information on vacant and undeveloped parcels

A statewide dataset, or integrated regional land use datasets prepared by the regional planning commissions, recording both land use and tax parcel information would be an ideal platform for refining strategic water supply planning and land protection priorities.

Section 5: SUMMARY

Aside from improvements in the methods and data due to use of new and more accurate data on water features and road networks, and the promise of even better accuracy in future updates using emerging technology and resources (see ***Recommendations for Further Enhancement*** later in this section), there are three important conclusions that flow from this update of the favorable gravel well analysis for 2010:

- The remaining stratified-drift aquifer resources suitable for large municipal well development are scarce and scattered statewide;
- Many of the best remaining high-yield stratified-drift aquifer resources are not located conveniently to growth areas in the state; and,
- The extent of land protection where these resources remain is a relatively small fraction of the most critical aquifer areas, and often ineffectual in terms of protecting the areas with the highest yield potential.

Fraction of a fraction

In the development of statistics for this 2010 FGWA update, a pattern of scarcity emerges which becomes more acute the closer one looks at the grand prize of groundwater resources: those areas in each aquifer study area that have the best potential for high-yield wells of 150 gpm or greater.

What follows are several key facts that result from this 2010 update study, arranged in a hierarchy to illustrate the fragmenting effects of urban development on the already scarce resource of our stratified-drift aquifers.

- The total area of the mapped stratified-drift aquifers in New Hampshire is about 805,500 acres, or ***only 14% of the state's land area.***

- Across the state, only about 246,000 acres, or 30% of the total aquifer area, remains after buffering potential threats to groundwater quality for wells pumping 75 gpm or more. ***Only 85,000 acres, or 34%, of the 246,000 acres*** appears to be suitable for municipal water well development of 75 gpm or greater based on transmissivity.

- Only 209,000 acres, or 26% of the total aquifer area remains after buffering potential threats to groundwater quality for wells pumping 150 gpm or more. ***Only 25,000 acres, or 12%*** of the 209,000 acres appears to be suitable for wells pumping 150 gpm or greater.

- ***Only about 17,300 acres, or 21%*** of the FGWA 300 area (stratified-drift aquifer areas that satisfy both yield requirements and water quality buffers for 75 gpm wells) is protected.

Recommendations for Further Enhancement

Experience with this 2010 update of the NHDES favorable gravel well analysis has pointed to several issue areas, which if addressed in future studies, would greatly improve the accuracy of the calculation of available aquifer area for new well sites and provide a better baseline for tracking trends statistically and spatially.

NHDES Database: The NHDES database for known and potential contamination sites is complex and ever-changing, but it represents a very solid and critical picture of the many types of actual and potential threats to groundwater quality resulting from human uses of the land. However, the data are not catalogued chronologically in terms of when the feature has been added to the database, or

when the project has been closed (remediated or determined not to be a threat) by NHDES. Archived data are also not available to help in reconstructing past baselines versus current trends. At this time, we can only see the present condition in the data available. Attention to these shortcomings would greatly enhance the usefulness of the data to various natural resource planning agencies and service providers.

Aquifer Mapping: Delineating favorable gravel well sites depends greatly on the accuracy of the underlying stratified-drift aquifer mapping. In the course of this project, discrepancies in the mapping were discovered that affect the results of the model; one issue is relatively easy to remedy, the other will take a major effort. Three of the aquifer study areas in the southeast (Middle and Lower Merrimack, and the Lamprey basins) were mapped with overlapping polygons which cause confusing double counts in the areal measurements. The Lower Merrimack basin is mapped with a collar extending beyond its boundary into the Middle Merrimack basin, and could be edited digitally in the GIS. This was done for the FGWA update using guidance from USGS. The Lamprey basin also overlaps into the Lower Merrimack basin, but in less predictable ways that will take will require judgment by professional hydrogeologists to correct.

The other, much larger project is to update the mapping in the Nashua aquifer study area, particularly with respect to transmissivity contours. Much of this basin is mapped at 0 to 2,000 square feet per day transmissivity, but the threshold for a 75 gpm well is 1,000 square feet per day. There may be other generalizations within the higher transmissivity contours. This is the oldest of the thirteen aquifer maps (1987), but covers one of the most rapidly urbanizing regions in the state, and so should be a priority for updating.

Current Land Use Data: The buffering protocol used in the FGWA depends a great deal on the NHDOT road and highway data as a proxy for a variety of land uses not detected by other means. The buffer zones are assumed to contain or provide the opportunity for land uses that would typically occur along existing and new roadways. This “first cut” analysis is appropriate for statewide or aquifer basin-wide assessments, but as has been noted in several areas earlier in this report, the accuracy of the favorable well site delineation is much greater when data are available that show what is actually happening on the ground at a given time. An ideal resource would be regional or statewide land use mapping similar to that produced in the CICEET study discussed above, and/or land ownership mapping (tax parcels) with coding relative to land use similar to that produced by the regional planning agencies.

Upgraded Urban Features Data: While this dataset is not expected to change significantly over time, except for a new transmission line or other infrastructure feature, it would be helpful and increase the accuracy of the FGWA delineation to establish the actual right-of way distances for these features, and generate a buffer data layer for use by planners and GIS operators in conducting local versions of the analysis. Using the buffers only, with generalized typing coded into the buffer data, would help mask security-sensitive features such as electric substations. Adding other urban land use features, such as cemeteries, gravel mining operations, etc., would also strengthen the usefulness and accuracy of the dataset.

Delineation Accuracy: Even with better land use data, this study finds that there is no replacement for detailed evaluation of land use boundaries using aerial photography. Not only will land uses that may affect groundwater quality be detected on favorable gravel well lands, but inappropriate buffering of private roads may be corrected, for example. This level of detail and accuracy is especially important to community planning, and is consistent with other data development and planning services available in the public sector (regional planning agencies) and in private consulting services.

APPENDICES

Appendix A: About Stratified-Drift Aquifers

Note: This appendix narrative is excerpted from the Guide to Identifying Favorable Areas to Protect Future Municipal Wells in Stratifed-Drift Aquifers, Vol l, NHDES-WD-99-3. It is included here to amplify and provide context for the work conducted in updating the FGWA, and as a useful reference for regional planners considering similar assessment at community scale. Some minor editing and reformatting of the original text has been done to maintain consistency with the structure of the current report.

Stratified-drift aquifers are commonly referred to as sand-and-gravel aquifers because they often are predominantly composed of sand and gravel deposits. Although "stratified drift" is the geologically more precise term, both descriptions may generally be used interchangeably without creating confusion. An understanding of these aquifers is critical to the protection of groundwater resources and development of public and private water systems.

In order to understand the stratified-drift map, which is the base map used for the favorable gravel well analysis, it is helpful to understand some of the terminology used to describe groundwater. This section of the guide describes some general concepts about stratified-drift aquifers and groundwater. Key words are given in bold text where they are first mentioned and/or defined.

Aquifer: An aquifer is any geologic formation which can transmit significant quantities of water to wells and springs. The term has been used to describe both unconsolidated sediments and the underlying bedrock. Any formation containing a layer or zone which is relatively permeable (i.e., able to transmit water with relative ease), which is saturated (i.e., filled to capacity with water), and lies adjacent to a less permeable material can generally be considered an aquifer. Aquifers may be in till, fractured bedrock, or stratified drift.

Till: Till refers to the *unsorted* mixture of earth material which was carried beneath, within, or on top of a glacier and then deposited. Deposits of till, generally 10-25 feet thick, cover the majority of the hillslopes and upland areas of New Hampshire. There are a variety of till types, but most exhibit a wide range in particle size from boulders to fine silts and clays. These materials were incorporated into the glacier as it advanced southeasterly across what is now New Hampshire. Underneath the glacier, material was smeared along the land's surface as compact deposits of **lodgement till** or **basal till**. Less dense deposits of **ablation till** were draped across the landscape when the glacier stagnated and melted in place. Many private water wells are dug in till. Although yields vary greatly seasonally and in different wells, well yields from till are generally less than 5 gallons per minute.

Bedrock: Bedrock is the solid material that underlies all unconsolidated material (soil, till, stratified drift) and makes up the earth's crust. In New Hampshire, where porous rock such as limestone or sandstone is rare, groundwater is available in fractures, or cracks, in bedrock. Hence,

fractured bedrock formations can serve as aquifers. The vast majority of home wells constructed since 1984 have been drilled in bedrock. While almost any site in New Hampshire can support a well with sufficient yield to serve a single-family home, *relatively few sites can support a municipal water supply well*.

Stratified-Drift Aquifers: Stratified-drift material, unlike till, is composed of glacial sediments transported and deposited by meltwater. It is *stratified* or sorted into discrete horizontal or dipping layers which reflect changes in depositional environments as the last continental ice sheet retreated 10,000 to 14,000 years ago. In general, the coarser sand and gravel deposits were laid down closer to the melting glacier, in swift-moving water. Among these ice-contact deposits are eskers, kames, kame terraces, and ice-contact deltas. All are characterized by sorted deposits in discrete layers.

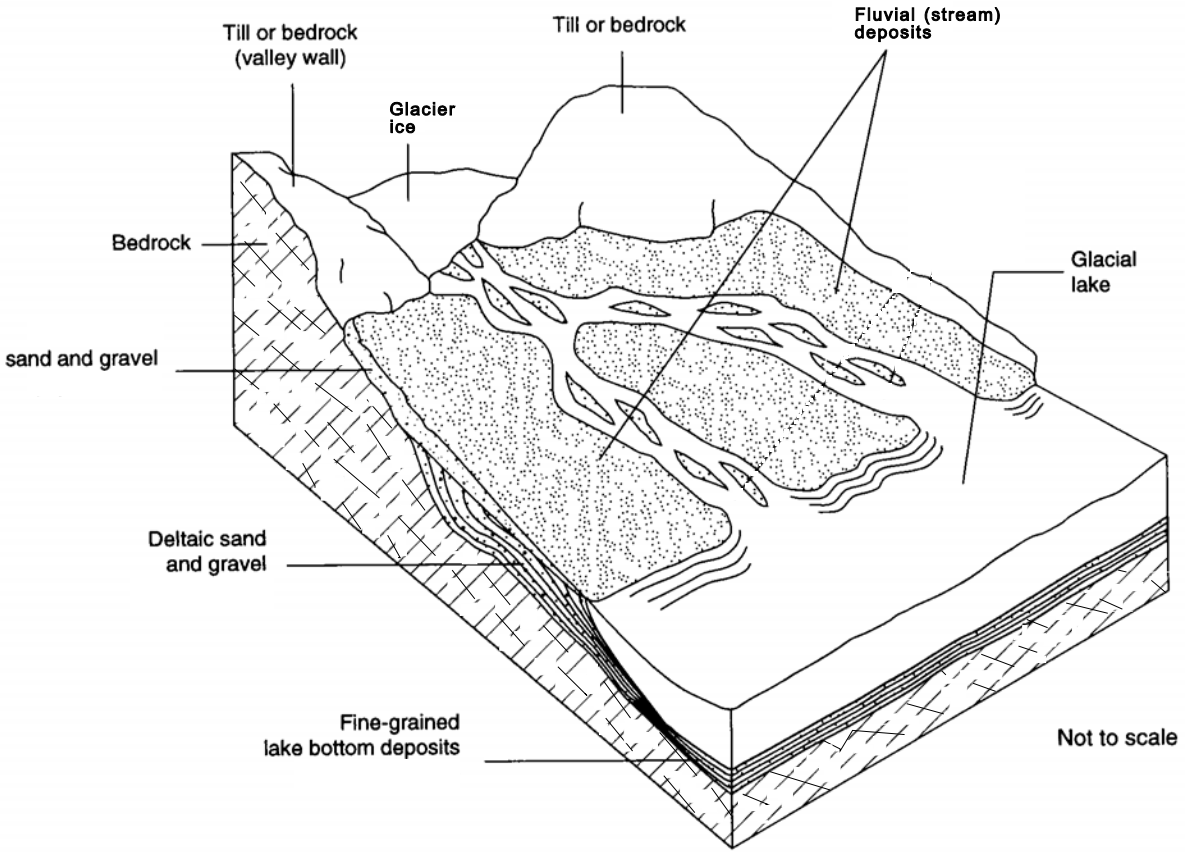
Sand and gravel deposits are often buried or surrounded by more fine-grained outwash sediments which were "washed out" of the melting ice front as it retreated further to the north. Where meltwater streams entered standing bodies of water, glacial lake deltas were formed. The finest sediments settled to the lake bottom in quieter water while coarser material formed fan-shaped delta deposits in the lake at the mouth of the stream. Over time, deltas advanced over the fine-grained lake bottom sediments into deeper waters of the lake.

Development of groundwater supplies in New Hampshire has been most successful in thick, saturated deposits of sand and gravel. These are stratified-drift aquifers. The coarser deposits are characterized by their high **hydraulic conductivity** which allows effective groundwater movement and storage. In contrast, fine-grained glacial lake sediments, in spite of their high capacity to store water, have a very low hydraulic conductivity because water is retained in the small pore spaces by the force of surface tension which inhibits free drainage.

Hydraulic conductivity: Hydraulic conductivity is an indication of the ease with which water may pass through *a given porous material*. In this report, it is measured in feet per day.

Saturated Thickness: Saturation is said to occur in a porous, permeable formation when all of the interconnected pores or fractures are filled with water. The saturated thickness of a stratified-drift aquifer is the difference between the elevation of the water table and the elevation of bedrock (or the bottom of the aquifer). This distance is measured in feet.

Transmissivity: Transmissivity is the product of the hydraulic conductivity of the aquifer material and the saturated thickness of the aquifer. Transmissivity measures the ability *of the aquifer* to produce water. Values of transmissivity are in units of feet^2 per day (feet per day X feet). It is important to understand that the most productive areas are characterized by deposits having both high hydraulic conductivity and significant saturated thickness.


Till or bedrock
(valley wall)
Till or bedrock
Fluvial (stream)
deposits
Glacier
ice
Bedrock
Glacial
lake
sand and gravel
Deltaic sand
and gravel
Fine-grained
lake bottom deposits
Not to scale

Appendix B: USGS Stratified-Drift Aquifer Maps

Note: This appendix narrative is excerpted from the Guide to Identifying Favorable Areas to Protect Future Municipal Wells in Stratifed-Drift Aquifers, Vol 1 GIS Operators Manual, NHDES-WD-99-3. It is included here to amplify and provide context for the work conducted in updating the FGWA, and as a useful reference for regional planners considering similar assessment at community scale. Some minor editing and reformatting of the original text has been done to maintain consistency with the structure of the current report.

The stratified-drift aquifer publications produced by US Geological Survey for each study area include a report plus sets of two map types. The first map type shows the raw data collected for the study together with information inferred from the raw data about the water table, stratified-drift deposits, and till deposits. The second map type shows further interpretation of the data with respect to the saturated thickness and transmissivity of stratified-drift aquifers. For the FGWA update project, two factors were used: the aquifer boundaries and the transmissivity zones. An explanation of these information layers follows.

Aquifer Boundaries: The boundaries between the different material types (e.g. stratified drift and till) are the result of the investigators' examination of data existing at the time of the investigation and extensive field work to collect new data. Because it is not feasible to collect and interpret data for all locations with equal confidence, three levels of aquifer boundary are indicated: approximately located, inferred, and concealed. These three levels are explained in the technical report that accompanies each set of stratified-drift aquifer maps. While stratified-drift aquifers are expected to be located within the boundaries shown on the maps, aquifer properties may vary considerably within a particular aquifer, or even within a portion of the aquifer. Because of variations in the flow of meltwater that deposited the aquifer materials, for example, there may be pockets of coarse (and hence highly conductive) material within larger deposits of fine material, or vice versa. ***Therefore, two factors dictate caution in how the map information is used:***

- uncertainty in the locations of aquifer boundaries, and
- uncertainty with respect to the uniformity of internal aquifer properties.

Transmissivity: As explained in the definitions in ***Appendix A***, transmissivity is a function of both aquifer saturated thickness and hydraulic conductivity. Transmissivity zones, as mapped by the USGS, are interpreted from estimated values for each of these key aquifer characteristics. *Saturated thickness* is derived from well completion reports filed with NHDES by licensed water well contractors upon completion of new wells. Auger holes, drilled specifically as part of the aquifer mapping program, provide more accurate data for both depths to bedrock and water-table elevations. *Hydraulic conductivity* of aquifer materials is estimated from grain size analyses of subsurface sediment samples obtained from auger holes. This information is augmented by well pump tests when possible. While areas of high transmissivity are the most important areas for the

development of water supplies, it is very difficult to equate transmissivity to well yield for a variety of reasons. As a well is pumped, the water table may drop. This reduces the saturated thickness which reduces the transmissivity, since transmissivity is the product of hydraulic conductivity and saturated thickness. Two aquifers with the same value for transmissivity do not necessarily have the same hydraulic conductivity and saturated thickness. However, transmissivity is still an excellent indicator of the potential of an aquifer to yield water.

For community-scale assessments of FGWA, the ***water table data*** associated with the aquifer mapping may be of use, indicating groundwater flow and connectivity among pockets of high-yield zones in the aquifer.

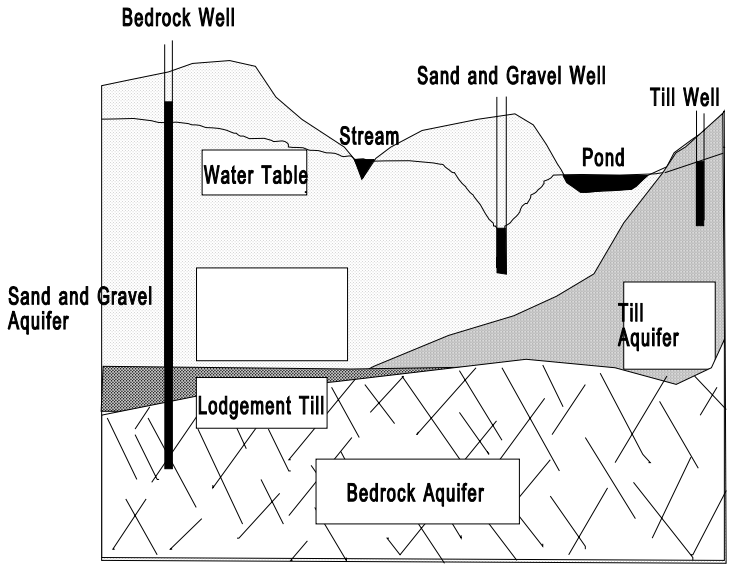


Figure 3: Water table

The water table is the uppermost elevation of the zone of groundwater saturation at a given location (figure 3). It is usually thought of as being below ground. However, at the edge of a lake, river or wetland, the water table intersects the land's surface. This condition also exists at naturally flowing seeps and springs. Water-table elevation contours may be read in the same way as land surface contours on a topographic map. Ground-water movement is inferred from the contours, based on the following principles:

1. Water always moves from higher to lower elevation, unless it is confined under pressure. For example, water in sand or bedrock trapped beneath an overlying layer of impermeable clay may be "pushed" by water from higher elevations to escape confinement. However, in the case of stratified-drift aquifers, most are unconfined, or confined only for short distances.
2. The direction of groundwater flow, at the water table, is perpendicular to water-table elevation contours. An exception to this may occur when ground water is confined within impermeable layers as mentioned above. Note also that the direction of

groundwater movement *at depth* may differ from the direction of movement at the water table.

3. Groundwater flows from areas of recharge to areas of discharge. Bodies of water such as streams and ponds may be fed by aquifer discharge where the water table intersects the surface. However, aquifers may also absorb water from streams, and less commonly lakes or ponds, where the surrounding water table is below the surface of the water body; and the aquifer material is coarse enough to allow percolation. This most frequently occurs where upland tributaries reach an aquifer, and occasionally where the main stream enters an aquifer. In such recharge zones there is a significant downward component of groundwater flow, whereas flow is upward in discharge zones.

4. The direction of groundwater flow may change in response to artificial disturbance, pumping, or storage. Examples of this may include construction projects which reroute drainage, pumping from public water supply wells, and the creation of impoundments for flood control or infiltration.

Appendix C: Table of Known and Potential Contamination Sites

This appendix is intended as a quick reference to the various data used in the buffering of known and potential contamination sites. All the NHDES ***project types*** used in the FGWA protocol are listed alphabetically below in **Table 1**.[13] These point-based data are derived from ten different GIS datalayer maintained by NHDES, and listed in **Table 2** below. GIS users wishing to obtain these data should contact DES's GIS Manager. (271-0399)

Table 1: NHDES Datalayers of Known and Potential Contamination Sites Used in the FGWA Protocol

Datalayer	Description	Source	Updated
c_site	Known/Potential Contamination sites	NHDES	monthly
c_area	Known/Potential Contamination polygons	NHDES	monthly
np_pt	Point/Non-Point Source Pollution sites.	NHDES	static
np_poly	Point/Non-Point Source Pollution polygons	NHDES	static
ust_site	Underground Storage Tanks.	NHDES	monthly
r_site	Hazardous Waste Generators (RCRA) Sites Includes small and large quantity waste generators.	NHDES	annually
r_area	Hazardous Waste Generators	NHDES	annually
Junkyd	Junkyard locations with at least 50 autos	NHDES	static
Npdes	National Pollution Discharge Elimination System Outfalls	NHDES	static

[13] Table 1 is an updated version of Table 3-7 in A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Aquifers, Vol. 2 GIS Operators Manual (1999). Pesticide application areas have not been used in this updated FGWA analysis due to concerns over the accuracy of the data.

Tri	Toxic Release Inventory (air, water, land)	USEPA	periodically

Table 2[14]: NHDES Known and Potential Contamination Site Project Types Used in the FGWA Protocol

Note: SPR means a sanitary protective radius of 300' or 400' depending upon well pumping rate. See discussion in report.

Project Type Acronym	Description	Buffer (ft)*	Comments
AST	Above ground storage tank	SPR	
CERCLA	Superfund Site	1000 minimum	Check with DES Waste Management on size of site, plume length and direction.
FUDS	Formerly used defense site	1000	Often large sites with multiple issues.
ETHER	Ether contaminated site	1000	Highly mobile and persistent contaminant.
FUEL	Leaking bulk storage facilities containing fuel oil	1000	
GWRELDET	Sites which have groundwater release detection permits and no other defined project type	1000	
IRSPILL	Initial response spill	1000	Small spills often remediated quickly but can involve substances with high contamination potential

[14] Table 2 is an updated version of Tables A-1 (Buffers for Known Contamination Sources) and A-2 Buffers for Potential Contamination Sites found in Appendix A of A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Aquifers, Vol. 2 GIS Operators Manual (1999).

H2O SAMPLE	Isolated groundwater sample (contaminated water supplies)	1000	Preliminary category. Further investigation would place the site into a different project type.
HAZWSTE	Hazardous waste project	1000	
HOLDING TANK	Example: temporary storage of garage wastes	SPR	
JUNKYD	Junkyards with more than 50 autos	1000	
LAND/LN	Lined landfills		
LAND/PRP	Proposed landfill	1000	High concentration of hazardous materials
LAND/UNLN	Existing unlined landfill or landfill closure	1000	High concentration of hazardous materials
LAST	Leaking above ground bulk storage facilities containing motor fuel	1000	
LUST	Leaking underground storage tank projects	1000	
LWW/LAG	Lined wastewater lagoon	1000	
NPDES	Pollution discharge to surface water	1000	Not an NHDES groundwater corrective action project type.
MOST	Leaking motor oil storage tank	1000	
OLD DUMP	Old Dump Sites (non-landfill)	SPR	Many “risk undetermined” but considered minimal.
OPUF	Leaking residential or commercial heating oil tanks	1000	
RAPIDINF	Rapid infiltration basins	1000	

RCRA	Resource Conservation & Recovery Act-registered hazardous waste handlers	SPR	Registered hazardous waste generator. Not necessarily a site of contamination.
SALT STORAGE COVERED		1000	
SALT STORAGE UNCOVERED		1000	
SEPT/LAG	Septage lagoons	1000	
SEPTIC	Subsurface wastewater disposal systems >20,000 gpd	1000	
SITEEVAL	Unsolicited site assessment or hazwaste types	1000	
SLUD/LAG	Sludge lagoons	1000	
SLUDGAP	Sludge application sites	SPR	DES permits this project type as appropriate recycling.
SNOW DUMPS		1000	Not an NHDES groundwater corrective action project type.
SPILL/RLS	Spill or release	1000	Larger spills with likely groundwater impacts
SPRAYIRR	Effluent spray irrigation projects	SPR	DES permits this project type as appropriate recycling.
STUMP/DEMO	Municipal or commercial stump or demo dump	1000	
TRANS.STA	Solid waste transfer stations with groundwater permits	1000	See GWRELDET above.
TRI	Toxic Release Inventory (air, water, land)	SPR	US EPA data. Local knowledge may warrant larger buffer.

UIC	Underground injection control-discharge of benign wastewaters not requiring a groundwater discharge permit or request to cease a discharge	SPR	i.e. floor drain closure requests
UST	Underground storage tank facilities	SPR	
UWW/LAG	Unlined wastewater lagoons	1000	

Appendix D: Aquifer Transmissivity and Potential Well Yield

Note: This appendix narrative is excerpted from the Guide to Identifying Favorable Areas to Protect Future Municipal Wells in Stratifed-Drift Aquifer, Vol 1 GIS Operators Manual, NHDES-WD-99-3. It is included here to amplify and provide context for the work conducted in updating the FGWA, and as a useful reference for regional planners considering similar assessment at community scale. Some minor editing and reformatting of the original text has been done to maintain consistency with the structure of the current report.

The USGS stratified-drift aquifer maps show aquifer transmissivity rather than potential well yields since the effort did not take into consideration well construction. For this analysis, "best" construction technology is assumed, and potential yields (Q) for wells developed in aquifers of a given transmissivity (T) are estimated on the basis of a relationship outlined by Krasny in *Ground Water*, Vol. 31, No 2, 1993, p 230:

$$Q \text{ (liters/second)} = 0.05 \text{ (liters/second/meters}^2\text{/day)} * T \text{ (meters}^2\text{/day)}$$

or

$$Q \text{ (gal/min)} = .0736257 \text{(gal/min/ft}^2\text{/day)} * T \text{ (ft}^2\text{/day)}$$

In his article, Krasny specified a range of well yields that could be associated with a given transmissivity. The above relationship is based on the minimum yield of these ranges.

Transmissivity ranges established by the USGS in the series of stratified-drift aquifer maps vary by study area, so it is impossible to develop a consistent set of projected well yields for all constraints analyses. The baseline stratified-drift aquifer maps represent USGS interpretations of discrete data points which are not uniformly distributed within the aquifer areas. The degree of uncertainty associated with these interpretations is greater where data are sparse. Due to this uncertainty, there can be no guarantee that a given well yield can be realized. In addition, many of the stratified-drift aquifers in New Hampshire occupy relatively narrow valley bottoms. Achieving 500+ gal/min yield from a well in such a deposit is difficult since the cone of depression will contact the upland boundary. Therefore, a conservative approach is taken for the favorable gravel-well analysis to ensure reasonable yield expectations on the part of map users:

A) The Q-T relationship used is based on the low end of the Krasny associated yield range for a given T as mentioned above.

B) Only the lower end of the USGS transmissivity range for a given aquifer area will be used to assign well yields.

C) The maximum approximate well yield used in a favorable gravel-well analysis is restricted to 300 gpm.

Well Yield Ranges Associated with Groundwater Transmissivity (per Krasny formula)

Transmissivity Shown in USGS Stratified-Drift Aquifer Maps (ft^2/d)*	Minimum Approximate Well Yield Used by Krasny (gal/min)	Approximate Well Yield for Constraints Analysis (gal/min)	Sanitary Protective Radius Used for Buffering of Urban Features (feet)
< 500	<37	Not used	Not used**
500-1000	37-74	Not used	Not used**
< 1000	<74	Not used	Not used**
1000-2000	74-147	75	300
1000-1500	74-110	75	300
1500-2000	110-147	110	400
< 2000	<150	<150	400
2000-3000	147-221	150	400
3000-4000	221-295	225	400
2000-4000	147-295	150	400
>4000	>295	300	400
4000-8000	295-589	300***	400
> 8000	>589	300***	400

* A variety of T ranges are shown here because different stratified-drift aquifer maps use different T ranges (based on the overall range of T in the specific USGS study area).

**Areas with these T values were not used in the Henniker analysis, since 75 gallons/minute was chosen as the minimum desirable well yield. Note that these areas will provide wells of lesser yields.

***Suggested well yield is limited to 300 gpm given the typical geometry of stratified-drift aquifers in New Hampshire.

In any particular constraints analysis, the selection of a T cutoff for use in outlining the portion of the aquifer area to be included depends on two factors: the ranges of T shown on the stratified-drift aquifer map for the study area and the desired well yield. First, the mapped ranges of T are matched with those in the first column of Table 1, then the well yield cutoff is chosen from among those in the third column corresponding to the mapped ranges of T.

Finally, it should be noted that Krasny assumed a 16.5 ft drawdown under pumping conditions in the production well for his analysis. Technically, this would restrict the Q-T relationship to areas where saturated thickness is at least 33 ft to ensure no more than a 50 percent drawdown. However, this constraint was not utilized in the favorable gravel-well analysis, since multiple small wells placed over a larger area could compensate for this limitation.

Alternative Method for Estimating Yield

The Maine State Geologic Survey uses an alternative approach based on David Mazzaferro's *Groundwater Availability and Water Quality in Farmington, Connecticut* (USGS Water-Resources Investigations, Open File Report 80-751, 1980) for estimating yield. The method is more complicated in that it requires the overlay of transmissivity and saturated thickness coverages in order to calculate the yield, and is based upon the following equation:.

$$Q = T * b / 750$$

where Q = well yield (gpm)
T = transmissivity (ft^2/d)
b = saturated thickness (ft)

Initial analysis revealed that the Mazzaferro method had the possibility of fine-tuning the calculated yield compared to the NHDES approach, due to the consideration of saturated thickness as a factor. After further investigation, NHDES chose to stay with the simpler approach based on transmissivity alone, for the following reasons:

1) An examination of well yield data, transmissivity, and saturated thickness data was unable to clearly demonstrate that one method was more accurate than the other. This is likely due to the fact that the available database was not intended for this effort (e.g. A given well was neither constructed nor always pumped to determine the maximum safe yield at its location, the database did not allow for possible induced infiltration of surface water, etc.).

2) In New Hampshire, the saturated thickness coverage is a line coverage and would have to be converted to a polygon coverage for the overlay process, complicating the process and increasing the cost.

3) The saturated thickness contour interval was often very coarse (e.g. 40 ft.), limiting the benefit that could be gained from this approach.

4) To apply the Mazzaferro equation, one must have great confidence in the spatial accuracies of both the transmissivity and saturated thickness GIS layers. This is due to the fact that both the transmissivity and saturated thickness GIS layers are spatial interpolations of point data and have the possibility of significant spatial errors. In the GIS overlay process, spatial errors are additive, such that the final product (Yield) has lower spatial accuracy than any given individual source layer.

Appendix E: Map Disclaimer

This disclaimer should accompany any maps or other publications produced using the NHDES favorable gravel well analysis method. Notes on data sources in such maps and publications need to reflect the correct, current revision date.

Disclaimer

This map represents the Favorable Gravel Well Analysis results completed according to the methodology within A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Areas: Updated Methodology & Data (SPNHF, June, 2010). Current GIS data, as of (enter Month and Year) was used in the analysis and is available from UNH GRANIT, state and federal agencies. It shows a computerized overlay analysis to determine remaining areas of stratified-drift aquifer potentially having both water yield and quality sufficient to serve as large public water supplies. Local land use information and further hydrogeologic analysis are essential to determine the suitability of any location as an actual well site. Buffers used to create this map do not guarantee protection from well contamination. The status of sites and associated buffers are subject to change when contamination has been cleaned up. Similarly, the existing source water protection areas may be revised as more site-specific hydrogeologic information becomes available.

The information provided in this map includes a subset of databases developed by the New Hampshire Department of Environmental Services. Development of these databases is ongoing and this map may not contain all existing and potential threats to groundwater. NHDES is not responsible for the use or interpretation of this information, nor any inaccuracies in site names, locations, projected yields, or groundwater flow direction. All information is subject to verification.

The data are intended for use at 1:24,000 scale. These data are not appropriate for site scale evaluations, and are to be used for regiona-l or community-scale planning, or educational purposes only.

Appendix F: Municipal Summary of SDA and FGWA 300/400

The following table lists all municipalities in New Hampshire alphabetically with data derived from the 2010 update of the FGWA model, the total area (acres) of stratified-drift aquifer in each community, remaining area suitable for high-yield and very high yield wells and the extent of land protection for each category. The numbers and totals listed may vary from other information in the body of the report due to rounding.

			FGWA 300 High-Yield Wells (>75 gpm)			FGWA 400 Very High-Yield Wells (>150 gpm)		
Municipality	**Total Acres SDA**	**Percent of Total Land Area**	**Total Acres Suitable**	**Total Acres Protected**	**Percent Protected**	**Total Acres Suitable**	**Total Acres Protected**	**Percent Protected**
Acworth	946	3.8%	15	0	0.0%	2	0	0.0%
Albany	5,141	10.7%	1,044	711	68.1%	444	309	69.5%
Alexandria	2,669	9.6%	840	19	2.3%	465	33	7.1%
Allenstown	3,088	23.8%	85	64	75.1%	34	0	0.0%
Alstead	831	3.3%	0	0		0	0	
Alton	4,298	10.6%	208	73	34.9%	7	1	10.4%
Amherst	8,402	38.9%	1,618	108	6.7%	793	47	5.9%
Andover	4,142	16.1%	669	90	13.5%	212	29	13.5%
Antrim	2,245	9.9%	103	0	0.0%	3	0	0.0%
Ashland	1,693	23.5%	349	1	0.2%	34	0	0.0%
Atkinson	473	6.6%	0	0		0	0	
Atkinson & Gilmanton	1,302	10.6%	0	0		0	0	
Auburn	4,809	29.6%	132	83	63.1%	20	16	78.1%
Barnstead	3,412	12.5%	0	0		0	0	
Barrington	5,421	18.2%	1,598	169	10.5%	25	0	1.5%
Bartlett	5,489	11.5%	1,324	105	7.9%	841	43	5.1%
Bath	5,500	22.8%	108	51	47.3%	10	4	42.7%
Beans Grant	1	0.0%	0	0		0	0	
Beans Purchase	0	0.0%	0	0		0	0	
Bedford	5,854	28.0%	33	2	7.2%	0	0	55.5%
Belmont	7,053	36.8%	409	96	23.5%	81	4	5.3%
Bennington	2,612	36.5%	239	25	10.3%	97	16	16.9%
Benton	600	1.9%	0	0		0	0	
Berlin	2,147	5.5%	84	32	37.7%	37	6	17.4%
Bethlehem	6,267	10.8%	159	4	2.5%	68	1	1.8%
Boscawen	3,729	23.7%	69	52	76.3%	47	38	79.9%
Bow	3,706	20.7%	191	0	0.0%	81	0	0.0%
Bradford	2,474	11.0%	61	1	1.8%	7	0	0.0%
Brentwood	3,529	32.9%	109	46	42.0%	23	10	46.0%
Bridgewater	1,628	11.8%	652	7	1.1%	15	0	0.0%
Bristol	1,865	17.4%	405	142	35.1%	140	121	86.3%
Brookfield	1,070	7.3%	338	43	12.8%	0	0	
Brookline	4,161	32.8%	1,166	87	7.5%	426	59	13.8%
Cambridge	4,921	15.1%	0	0		0	0	
Campton	4,050	12.2%	878	171	19.5%	260	50	19.4%

Canaan	5,360	15.8%	164	36	22.1%	22	0	0.0%
Candia	1,859	9.6%	13	0	0.0%	0	0	
Canterbury	4,538	16.2%	62	1	1.3%	20	0	0.3%
Carroll	6,828	21.3%	507	97	19.2%	104	15	14.6%
Center Harbor	341	4.0%	17	5	31.1%	0	0	
Chandlers Purchase	0	0.0%	0	0		0	0	
Charlestown	6,069	26.7%	405	18	4.4%	71	5	7.1%
Chatham	2,596	7.2%	410	78	19.0%	120	23	19.6%
Chester	2,987	18.0%	0	0		0	0	
Chesterfield	1,359	4.7%	28	0	0.0%	11	0	0.0%
Chichester	732	5.4%	7	0	0.0%	0	0	
Claremont	6,043	22.0%	304	131	43.1%	151	76	50.5%
Clarksville	1,051	2.7%	19	0	0.0%	5	0	0.0%
Colebrook	3,560	13.7%	177	62	35.1%	107	37	34.7%
Columbia	1,916	4.9%	247	66	26.8%	127	30	23.5%
Concord	19,979	49.1%	549	121	22.0%	114	7	6.2%
Conway	14,240	32.0%	2,277	307	13.5%	1,776	261	14.7%
Cornish	1,702	6.3%	4	0	0.0%	0	0	
Crawfords Purchase	91	1.7%	0	0		0	0	
Croydon	582	2.5%	20	0	0.0%	4	0	0.0%
Cutts Grant	0	0.0%	0	0		0	0	
Dalton	2,643	15.0%	280	0	0.0%	17	0	0.0%
Danbury	3,008	12.5%	451	42	9.3%	23	0	1.1%
Danville	387	5.2%	0	0		0	0	
Deerfield	3,179	9.8%	8	0	0.0%	0	0	
Deering	2,612	13.5%	412	79	19.1%	23	0	0.0%
Derry	3,599	15.9%	16	3	16.3%	4	1	33.4%
Dixs Grant	306	2.4%	0	0		0	0	
Dixville	853	2.7%	0	0		0	0	
Dorchester	532	1.9%	172	4	2.3%	0	0	
Dover	12,965	75.9%	3,630	1,101	30.3%	84	54	63.8%
Dublin	919	5.1%	25	1	3.6%	0	0	
Dummer	1,187	3.9%	16	0	0.0%	0	0	
Dunbarton	1,091	5.8%	0	0		0	0	
Durham	738	5.2%	73	40	54.6%	39	23	58.4%
East Kingston	678	10.7%	0	0		0	0	
Easton	2,192	11.0%	277	0	0.2%	128	0	0.0%
Eaton	1,319	8.5%	29	11	36.2%	8	6	73.9%
Effingham	10,080	40.6%	1,528	478	31.3%	211	33	15.6%
Ellsworth	0	0.0%	0	0		0	0	
Enfield	2,111	8.2%	9	0	0.0%	0	0	0.0%
Epping	2,494	15.1%	22	1	3.7%	0	0	
Epsom	2,713	12.4%	85	4	4.3%	21	1	6.2%
Errol	5,815	15.0%	61	2	2.8%	1	0	34.6%
Ervings Location	0	0.0%	0	0		0	0	
Exeter	1,815	14.5%	91	62	68.2%	2	0	9.5%
Farmington	2,560	11.0%	603	12	2.0%	71	12	17.1%
Fitzwilliam	1,724	7.8%	3	0	0.0%	0	0	
Francestown	2,832	14.9%	47	11	23.0%	0	0	
Franconia	2,954	7.0%	494	204	41.3%	217	30	13.7%

Franklin	5,110	29.2%	938	694	74.0%	798	656	82.2%
Freedom	5,921	26.8%	1,088	377	34.7%	415	255	61.5%
Fremont	4,180	37.9%	0	0		0	0	
Gilford	3,635	14.7%	181	37	20.6%	9	0	4.9%
Gilmanton	1,461	4.0%	25	0	0.0%	1	0	0.0%
Gilsum	719	6.8%	3	0	0.0%	0	0	
Goffstown	3,425	14.5%	70	36	51.0%	40	24	60.6%
Gorham	3,183	15.6%	25	0	0.2%	3	0	0.0%
Goshen	1,462	10.2%	8	0	0.0%	0	0	
Grafton	1,780	6.7%	298	0	0.0%	7	0	0.0%
Grantham	488	2.8%	2	0	0.0%	0	0	0.0%
Greenfield	5,239	31.0%	679	244	36.0%	325	191	58.6%
Greenland	1,738	25.6%	36	11	31.1%	10	0	0.0%
Greens Grant	192	8.2%	0	0		0	0	
Greenville	168	3.8%	0	0		0	0	
Groton	604	2.3%	151	3	1.8%	37	2	4.0%
Hadleys Purchase	0	0.0%	0	0		0	0	
Hales Location	343	21.5%	103	82	79.4%	59	45	76.0%
Hampstead	1,473	17.2%	0	0		0	0	
Hampton	1,612	20.9%	61	18	29.0%	10	8	73.6%
Hampton Falls	195	2.3%	0	0		0	0	
Hancock	2,463	12.9%	36	20	55.7%	9	4	46.3%
Hanover	3,402	10.8%	123	44	36.0%	54	20	36.5%
Harrisville	815	6.8%	80	7	9.2%	1	0	0.3%
Harts Location	1,551	12.7%	208	182	87.4%	146	134	91.9%
Haverhill	9,363	28.7%	198	18	9.1%	27	7	23.8%
Hebron	784	7.3%	261	41	15.6%	153	34	22.4%
Henniker	3,932	14.7%	414	161	38.8%	228	103	45.3%
Hill	1,149	6.8%	280	191	68.2%	179	129	71.7%
Hillsborough	3,647	13.2%	194	36	18.3%	43	2	5.4%
Hinsdale	4,664	35.6%	715	0	0.0%	62	0	0.0%
Holderness	2,300	11.8%	684	46	6.8%	1	0	0.0%
Hollis	7,279	36.0%	2,371	630	26.6%	880	369	41.9%
Hooksett	5,344	23.2%	400	12	2.9%	153	3	2.0%
Hopkinton	9,769	37.0%	584	37	6.4%	111	18	16.5%
Hudson	7,116	39.3%	1,199	103	8.6%	33	1	3.1%
Jackson	1,134	2.7%	8	0	0.0%	0	0	
Jaffrey	3,336	13.6%	251	0	0.1%	13	0	0.0%
Jefferson	1,954	6.1%	16	0	0.0%	0	0	
Keene	6,593	28.0%	510	68	13.3%	235	39	16.6%
Kensington	1,451	19.0%	22	4	18.8%	0	0	0.0%
Kilkenny	0	0.0%	0	0		0	0	
Kingston	7,072	56.6%	359	122	33.9%	100	44	44.5%
Laconia	1,573	12.4%	8	0	0.0%	0	0	
Lancaster	4,770	14.9%	55	0	0.0%	20	0	0.0%
Landaff	747	4.1%	0	0		0	0	
Langdon	1,820	17.6%	5	0	0.0%	3	0	0.0%
Lebanon	4,600	17.9%	70	19	27.2%	30	13	42.5%
Lee	2,752	21.7%	79	5	5.9%	12	0	0.0%
Lempster	2,067	10.0%	31	0	0.0%	2	0	0.0%

Lincoln	2,557	3.1%	878	802	91.3%	21	20	95.9%
Lisbon	4,044	24.1%	264	18	6.9%	89	12	13.5%
Litchfield	9,004	94.9%	2,330	329	14.1%	209	17	8.1%
Littleton	4,143	13.0%	1	0	0.0%	0	0	0.0%
Londonderry	6,993	26.1%	337	68	20.3%	17	0	0.0%
Loudon	3,687	12.5%	461	75	16.3%	121	45	37.4%
Low & Burbanks	0	0.0%	0	0		0	0	
Lyman	1,042	5.7%	32	0	0.0%	0	0	
Lyme	3,412	9.9%	65	27	41.2%	0	0	
Lyndeborough	1,514	7.9%	556	132	23.8%	18	0	0.0%
Madbury	2,814	38.0%	963	262	27.2%	83	25	30.4%
Madison	5,783	23.5%	1,210	432	35.7%	713	364	51.1%
Manchester	11,849	56.4%	0	0	0.0%	0	0	
Marlborough	342	2.6%	0	0		0	0	
Marlow	1,028	6.2%	1	0	0.0%	0	0	
Martins Location	347	14.6%	0	0		0	0	
Mason	2,217	14.5%	4	0	0.0%	0	0	
Meredith	1,658	6.5%	32	1	1.8%	12	0	0.0%
Merrimack	12,024	58.2%	1,992	270	13.5%	249	52	20.7%
Middleton	102	0.9%	24	0	0.0%	0	0	
Milan	4,387	10.8%	207	0	0.0%	109	0	0.0%
Milford	5,936	36.8%	1,865	295	15.8%	562	182	32.4%
Millsfield	258	0.9%	0	0		0	0	
Milton	2,268	10.8%	553	275	49.6%	51	12	24.5%
Monroe	3,209	22.4%	151	3	2.2%	71	2	2.5%
Mont Vernon	260	2.4%	75	0	0.5%	0	0	
Moultonborough	4,669	12.2%	55	0	0.0%	0	0	
Nashua	14,162	72.5%	1,549	484	31.2%	668	384	57.4%
Nelson	473	3.4%	0	0		0	0	
New Boston	6,080	22.3%	221	53	24.1%	41	1	1.9%
New Castle	0	0.0%	0	0		0	0	
New Durham	3,641	13.8%	247	56	22.9%	41	14	33.9%
New Hampton	3,613	15.3%	976	257	26.4%	394	220	55.9%
New Ipswich	3,745	18.0%	132	13	9.9%	30	8	26.7%
New London	802	3.5%	36	3	9.8%	2	1	66.9%
Newbury	1,320	9.3%	149	0	0.0%	69	0	0.0%
Newfields	506	11.1%	13	0	0.0%	0	0	
Newington	2,042	39.2%	0	0		0	0	
Newmarket	671	8.3%	38	3	7.5%	4	0	0.0%
Newport	3,926	14.2%	104	5	4.6%	42	1	2.8%
Newton	2,575	41.2%	28	9	32.1%	6	0	0.0%
North Hampton	1,997	22.5%	87	14	15.9%	30	1	3.6%
Northfield	1,977	10.8%	21	0	0.0%	0	0	
Northumberland	4,381	19.2%	476	157	33.0%	138	72	51.9%
Northwood	260	1.4%	0	0		0	0	
Nottingham	2,106	7.0%	0	0		0	0	
Odell	1	0.0%	0	0		0	0	
Orange	645	4.4%	89	40	44.8%	0	0	
Orford	3,595	12.1%	176	2	1.2%	52	0	0.0%
Ossipee	15,709	34.8%	3,798	1,223	32.2%	1,578	525	33.3%

Pelham	6,283	37.8%	376	51	13.5%	166	33	19.7%
Pembroke	3,468	24.2%	601	32	5.3%	227	20	8.7%
Peterborough	5,815	24.1%	345	83	24.0%	94	20	21.0%
Piermont	2,538	10.3%	0	0		0	0	
Pinkham's Grant	14	0.6%	0	0		0	0	
Pittsburg	11,774	6.5%	343	82	24.0%	234	45	19.4%
Pittsfield	223	1.5%	0	0		0	0	
Plainfield	2,050	6.1%	0	0		0	0	
Plaistow	3,265	48.3%	60	4	6.1%	0	0	
Plymouth	3,960	22.1%	1,445	32	2.2%	9	0	0.0%
Portsmouth	3,289	32.9%	12	0	0.0%	1	0	0.0%
Randolph	757	2.5%	7	0	0.0%	0	0	
Raymond	3,854	20.9%	39	10	26.3%	2	2	84.3%
Richmond	681	2.8%	107	0	0.0%	37	0	0.0%
Rindge	3,299	13.9%	158	125	79.2%	60	52	86.3%
Rochester	11,285	39.9%	2,551	220	8.6%	220	43	19.5%
Rollinsford	3,616	77.3%	1,337	248	18.5%	0	0	
Roxbury	62	0.8%	0	0		0	0	
Rumney	4,048	15.2%	1,708	9	0.5%	266	0	0.0%
Rye	1,696	21.2%	24	1	3.6%	5	0	0.2%
Salem	4,928	31.2%	79	5	6.2%	0	0	0.0%
Salisbury	3,904	15.5%	52	13	25.8%	0	0	
Sanbornton	3,928	12.9%	1,447	271	18.7%	1,247	231	18.5%
Sandown	2,379	26.8%	1	0	45.8%	0	0	
Sandwich	4,669	8.0%	599	0	0.0%	358	0	0.0%
Sargents Purchase	0	0.0%	0	0		0	0	
Seabrook	519	9.1%	33	12	36.4%	6	6	91.7%
Second College	2,926	11.1%	0	0		0	0	
Sharon	2,320	23.2%	120	70	58.6%	53	37	69.6%
Shelburne	3,609	11.8%	610	10	1.6%	416	1	0.3%
Somersworth	4,216	67.8%	856	34	3.9%	5	3	54.5%
South Hampton	461	9.1%	0	0	0.0%	0	0	
Springfield	552	2.0%	5	0	0.0%	0	0	0.0%
Stark	3,962	10.5%	496	43	8.6%	246	9	3.9%
Stewartstown	2,122	7.2%	123	0	0.0%	103	0	0.0%
Stoddard	429	1.3%	0	0		0	0	
Strafford	1,377	4.4%	113	1	1.2%	0	0	
Stratford	3,951	7.8%	415	91	22.0%	304	53	17.4%
Stratham	1,336	13.8%	2	0	0.0%	0	0	
Success	1,693	4.7%	0	0		0	0	
Sugar Hill	324	3.0%	45	42	94.0%	18	18	100.0%
Sullivan	81	0.7%	0	0		0	0	
Sunapee	392	2.9%	0	0	0.0%	0	0	
Surry	1,383	14.0%	25	15	59.4%	10	6	59.4%
Sutton	4,006	14.8%	93	39	41.6%	2	0	0.0%
Swanzey	7,494	26.3%	1,356	51	3.8%	751	37	4.9%
Tamworth	9,799	25.7%	2,050	611	29.8%	1,121	357	31.8%
Temple	2,057	14.5%	0	0		0	0	
Thompson & Meserve	0	0.0%	0	0		0	0	
Thornton	5,489	17.1%	1,598	94	5.9%	651	14	2.2%

Tilton	2,078	29.1%	77	0	0.1%	0	0	
Troy	684	6.1%	0	0	0.0%	0	0	
Tuftonboro	5,424	20.9%	261	2	0.8%	18	0	0.0%
Unity	692	2.9%	0	0		0	0	
Unorganized Territory	306	0.8%	0	0		0	0	
Wakefield	5,712	22.6%	795	2	0.3%	208	0	0.0%
Walpole	5,031	22.3%	62	28	45.2%	35	21	61.7%
Warner	4,174	11.9%	119	38	31.6%	17	6	32.1%
Warren	1,628	4.0%	459	15	3.2%	108	0	0.0%
Washington	438	1.5%	1	0	0.0%	0	0	0.0%
Waterville Valley	1,587	5.1%	609	581	95.5%	12	11	94.5%
Weare	5,065	14.0%	186	30	16.3%	5	0	0.0%
Webster	4,415	24.9%	174	108	61.7%	40	30	76.2%
Wentworth	2,514	6.1%	828	85	10.2%	186	0	0.0%
Wentworths Location	1,104	9.4%	0	0		0	0	
Westmoreland	2,140	9.3%	44	1	1.8%	0	0	
Whitefield	3,261	14.9%	73	18	24.5%	14	12	80.0%
Wilmot	1,876	10.0%	102	0	0.0%	1	0	0.0%
Wilton	3,370	20.7%	1,207	299	24.8%	97	62	64.2%
Winchester	5,319	15.2%	347	12	3.4%	198	6	3.2%
Windham	2,248	13.2%	47	6	11.7%	0	0	
Windsor	875	16.7%	0	0		0	0	
Wolfeboro	4,011	13.1%	13	0	0.0%	0	0	
Woodstock	2,425	9.1%	477	70	14.7%	115	10	9.0%
Totals			**84,557**	**17,304**	**20.5%**	**24,953**	**6,608**	**26.5%**

Appendix G: GIS Analyst Data

Background

For additional context and more information on the development of the GIS aspect of the FGWA model, see *A Guide to Identifying Potentially Favorable Areas to Protect Future Municipal Wells in Stratified-Drift Aquifers, Volume 2 GIS Operator's Manual January 1999***,** available as an electronic file from NHDES. Many similarities exist between the 1999 and the 2010 modeling effort that may be helpful to GIS analysts unfamiliar with the model or the data. However, the model design and data sources cited in the full technical report, and in the processing notes below, should take precedence.

Purpose:

The intent of this appendix is to provide GIS analysts with sufficient guidance regarding GIS processing to replicate or improve the buffering procedures used to update the FGWA in 2010. This assumes the operator has a relatively advanced understanding and capability with ArcGIS 9.3, the ESRI software platform used in this analysis, including data management, various data layer processing functions (union, merge, clip, erase, etc.), and the ability to manipulate tabular data and develop query language.

Old (pre-2010) FGWA Data v. New (2010) FGWA datasets:

Earlier FGWA datasets provided by NHDES (*hyt4_nh.shp*, *u400_des.shp*, etc.) did not benefit from more recent and more detailed published GIS data now available. The 2010 FGWA update employed four buffer regimes discussed in the main body of the report: hydrological buffers, transportation buffers, contamination site buffers, and urban features buffers. The pertinent statewide buffer datasets are listed below and are available from NHDES. (Note that the suffix spr300 and spr400 refer to subsets of the buffer data that are derived from differing sanitary protective radius inputs.)

- *FGWA2010_hydrological_buffer_2010.shp*
- *FGWA2010_transportation_buffers_spr300.shp*
- *FGWA2010_transportation_buffers_spr400.shp*
- *FGW2010_contaminationsites_buffers_spr300.shp*
- *FGW2010_contaminationsites_buffers_spr400.shp*
- *FGWA2010_urbanfeatures_buffers_spr300.shp*
- *FGWA2010_urbanfeatures_buffers_spr400.shp*

GIS analysts may choose to improve or update the buffers with local data by manually amending them or employing standard GIS algorithms (clipping or erasing) to reduce error or to add data where new information may improve or supersede the 2010 NHDES buffers. Alternatively, the entire suite of buffers can be rebuilt using local or regional base information.

It should also be noted that a special, edited and expanded version of the USGS aquifer data has been generated for the FGWA update, with the file name *FGWA2010_ aquiferarea.shp*. As

mentioned in the report, this was necessary due to overlapping polygons in three aquifer study areas in southeastern N.H. This edited aquifer data is provisional only, and was created based on limited guidance from staff at USGS. One of the recommendations of this study is that the statewide aquifer data from USGS be revised with input from professional hydro-geologists. More detailed local or regional FGWA studies should consider consulting with USGS to assure best-available base data.

Note that *FGWA_ aquiferarea.shp* contains a ***GPM_code*** field that allows aquifer features to be queried by potential yield class, as described in the report.

GIS operators involved in generating updated FGWA data with more current or more accurate data inputs are encouraged to contact NHDES Source Water Protection Program staff regarding incorporation of revised data into the statewide FGWA data library.

System Requirements:

A GIS work station capable of running ArcGIS 9.3 is required to replicate the GIS processing laid out below. Manipulating regional or statewide datasets requires maximum processing power (with little or no multi-tasking at the work station) and a careful, step-wise approach to avoid failure due to "out of memory" or other errors. This is especially true of erase operations. For example, the statewide FGWA dataset prepared in the 2010 update could only be run on a basin-by-basin basis for thirteen basins individually, and then merged to produce a statewide coverage.

It is also necessary to download and run an ArcGIS extension called XTools which is the only way to conduct erases of data and which allows rapid updating of areal measurements (perimeter, area, acres) in the attribute tables of data derived from various processing steps. This software is available at http://www.xtoolspro.com/, but other third party software extensions may be available and appropriate to the tasks.

Processing Overview:

In brief, the computerized FGWA analysis involves the buffering of various features that represent potential or known sources of contamination to a drinking water source well. The four buffer regimes are discussed in detail, and the resulting statewide buffer datasets are listed above. Once these buffers are generated, they are subtracted from the full extent of stratified drift aquifer using an erase process in the GIS, leaving the "potentially favorable gravel well areas."

Other important guidance includes the following:

- Many datasets used in the FGWA process contain data that are not used in the analysis, and therefore require a Definition Query be done to limit the data being processed. In the process steps below this step will use the abbreviation ***DQ***.

- *Italics* are used in the process description below where known filenames for certain data exist, or are in common use, Boldface ***italics*** are also used to emphasize the field heading used in certain ***DQ***.

- Processing speed will be improved if extraneous fields in the data are deleted. Do not delete fields critical to spatial location of features.

- Please see the main body of the report for explanation of the rationale for use of specific datasets.

- ArcGIS 9.3 allows a union of only two datasets at a time, therefore, multiple union steps are necessary to generate a final union that reflects all buffers. ***It is imperative that the GIS operator be meticulous in managing data developed step-wise, either in union processing or during erases.*** Regular back-ups of derivative shapefiles and .mxd files are recommended.

Process Steps:

Step 1: Hydrologic Buffer

a) Download the most current version of the following hydrographic datasets from the GRANIT data library at http://www.granit.unh.edu/data/downloadfreedata/downloaddata.html:

   - *New Hampshire Hydrography Dataset*, which contains:
     NHDflowline.shp
     NHDarea.shp
     NHDwaterbody.shp

   - *National Wetlands Inventory*

b) Clip data to interest area to reduce processing. A 1,000 foot buffer outside the aquifer study area is recommended.

c) DQ *NHDflowline.shp* ***Ftype*** <> 460 to remove intermittent streams.

d) Select for wetlands in NHDwaterbody.shp and create derivative NHD wetlands datalayer (***Descript*** = swamp/marsh), then DQ <> Descript swamp/marsh.

e) Union NWI and NHD wetlands to create a single wetland datalayer, dissolve, and convert multi-part shapes to single part. Recalculate Acres.

f) Buffer features in NHDflowline.shp, NHDwaterbody.shp, and the unioned wetlands data by 50 feet.

g) Union the resulting buffer data, dissolve, convert to single part shapes, and recalculate Acres. Note that ArcGIS 9.3 allows a union of only two datasets at a time, therefore, multiple union steps are necessary to generate a final union that reflects all buffers.

h) This union may be used to erase features in *FGWA_aquifer_transmissivity.shp* at this point, **as part of an iterative series of erases,** or set aside for a master union of all buffer features later.

Step 2: Transportation Buffer

a) Download the most current version of NHDOT's *N.H. Public Roads* data, filename = *roads_dot.shp* from GRANIT.
b) Clip data to interest area.
c) Review *Roads Data Dictionary* which accompanies downloaded NHDOT data. Note coding for functional classes which is used to create a coding class later in this processing step.
d) DQ *roads_dot.shp* ***Legis_clas*** <> VI to remove Class 6 roads.
e) Add Field named ***FGWA_class*** to attribute table. Run data queries as follows, and code ***FGWA_class*** appropriately for buffer width according to functional class in table below (see also explanation in main body of report). Note that there are coding inconsistencies within the *roads_dot.shp* dataset that require queries across two attributes for certain FGWA buffer classes. For example, municipal roads require a DQ of four DOT functional codes plus one legislative class code. See query coding table below.
f) Note also that local road classifications may vary from NHDOT data, and should prevail when differences are verifiable with municipalities, especially in the case of Class 6 roads.

Transportation Query Coding

FGWA Buffer Class	DOT Functional Class Codes	Legislative Class Codes	LC_legend
Interstate Highways	1,11		
Primary Highways	2,12,14		
Secondary Highways	6,7,8,16		
Municipal Roads	9,16, 17,19	V	
Recreation Roads		III	
Private Roads	0		Private
Federal Roads		VII	

g) Generate the road buffers according to ***FGWA_class*** coding in step e) above. Note that <u>two</u> road buffer datasets must be generated: one for SPR = 300 feet, and another for SPR = 400 feet. See table below for road buffer distances by functional class for both SPR 300 and SPR 400.

Transportation Buffer Distances by Functional Class

DOT Functional Class	ROW	SPR 300 Buffer	SPR 400 Buffer
Interstate	100 - 150	375	475
Primary	100 - 150	375	475
Secondary	50 - 100	350	450
Municipal (Class 5)	50 - 75	338	438
Private Recreation	50 - 75	338	438
Federal	50 - 75	338	438
Recreation	50 - 75	338	438

h) Union the various buffers, dissolve, convert to single part shapes, and recalculate Acres. Note that ArcGIS 9.3 allows a union of only two datasets at a time, therefore, multiple union steps are necessary to generate a final union that reflects all buffers.

i) As above, use the final transportation buffer shapefile to erase aquifer features, or set aside for a master union.

Step 3: Known and Potential Contamination Sites

a) Obtain the necessary datasets from NHDES found in **Table 1** in **Appendix C**.
b) Also obtain *cst_projtype_lut.dbf* from NHDES in its most current form. This database look up table is key to sorting project types by activity.
c) Join *cst_projtype_lut.dbf* to both *Csite.shp* and *Carea.shp* using the DESID field. DQ for ***Proj_type*** <> I to be sure only Active projects are being used in the analysis.
d) Buffer ***Proj_type*** features by the distances listed in **Table 2** in **Appendix C** of the report. Note that two buffer datasets must be generated: one for SPR = 300 feet, and another for SPR = 400 feet.
e) Generate appropriate buffers for all other features not included in the *Csite.shp* and *Carea.shp* datalayers, including junkyards, npdes features (active only), np_poly and np_pt, r_site and r_area, tri, ust, and ast.
f) Union the various buffers, dissolve, convert to single part shapes, and recalculate Acres. Note that ArcGIS 9.3 allows a union of only two datasets at a time, therefore, multiple union steps are necessary to generate a final union that reflects all buffers.
g) As above, use the final contamination sites buffer shapefile to erase aquifer features, or set aside for a master union.

Step 4: Urban Features

a) Download *pipelines.shp* and *railroads.shp* from GRANIT. Note: *Pipelines.shp* contains other urban features such as transmission lines.
b) DQ *railroads.shp* for active features only where ***First_RR*** = Active and ***Type*** = Name or Active.
c) Buffer features according to distances as found in the table below, using the ***Type*** field to make queries that assign various buffer distances to features.
d) Union the various buffers, dissolve, convert to single part shapes, and recalculate Acres. Note that ArcGIS 9.3 allows a union of only two datasets at a time, therefore, multiple union steps are necessary to generate a final union that reflects all buffers.
e) As above, use the final urban features buffer shapefile to erase aquifer features, or set aside for a master union.

Urban Feature Buffers

Urban Feature	SPR 300 Buffer	SPR 400 Buffer
Transmission Lines	475	575
Pipeline	338	438
Telephone Line	338	438
Power Station	300	400
Substation	300	400
Hydro Plant	300	400
Airport	300	400
Other	300	400

Step 5: Union/Erase

As mentioned above, there are two approaches to producing the final favorable gravel well spatial data: a series of erases, or to union the buffer datasets and make one erase. Either option is very processing-intensive, so large geographic areas may require segregation into several smaller areas, and a final merge of resulting FGWA.

It is recommended that all buffer datasets be dissolved and converted to single part shapes to ease processing.

Step 6: Protection Status

GIS analysts wishing to determine the status of land protection on FGWA datasets should download the most current Conservation and Public Lands datalayer from GRANIT, then perform an Intersect on the FGWA, update the Acres calculation, and summarize by yield class to stratify the data and develop statistics on the high-yield and very high-yield areas remaining within the FGWA of interest.

Questions:

While it is not the intent of the Forest Society to offer ongoing assistance to GIS analysts attempting to generate updated FGWA datasets, questions about and/or suggestions for improved processing of GIS data can be directed to:

Dan Sundquist
Director of Land Conservation Planning
Society for the Protection of NH Forests
Concord, NH 03301

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No telephone calls, please.