Long-Term Groundwater Monitoring Strategy and Plan
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Agricultural Chemicals and Groundwater Protection Program

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I. Introduction

The Agricultural Chemicals and Groundwater Protection Act (C.R.S. 25-8-205.5) established the Agricultural Chemicals and Groundwater Protection Program (Program) and mandated monitoring for nitrate-nitrogen from commercial fertilizers and pesticides in groundwater. Prior to passage of C.R.S. 25-8-205.5, a general absence of data prevented an accurate assessment of impacts to Colorado's groundwater quality due to agricultural operations. One of the Program's objectives is to provide current, scientifically valid, groundwater quality data to the Commissioner of Agriculture that can then be used to assess whether agricultural operations are impacting groundwater quality. Another Program objective is to assist the Commissioner in identifying those aquifers that are vulnerable to contamination. The Program also develops a variety of educational materials, including Best Management Practices (BMPs) and Fact Sheets, to assist in achieving the Program's goals. Thus, the Program has developed a multifaceted approach to protecting groundwater resources, while allowing for the proper and correct use of agricultural chemicals.

The groundwater quality-sampling program (Monitoring Program) is a key component in assessing potential problems regarding impacts to groundwater quality in agricultural areas. The Monitoring Program has two broad goals:

1. Determine if agricultural chemicals are present in groundwater.
2. Utilize the data collected to prevent groundwater contamination from agricultural chemicals.

The first goal is the mechanism by which the Program collects data to assess whether agricultural chemicals have impacted groundwater quality. Historically, the Program has systematically sampled groundwater quality throughout the State with the intent to identify areas where impacts due to agricultural chemicals may have already occurred. This sampling provides a baseline to assess potential future impacts, as well as trends in groundwater quality.

The second broad goal relies on the culmination of all of the Program's activities; including education, aquifer vulnerability identification, agricultural chemical storage and mixing/loading regulations, and waste pesticide collection and disposal to protect groundwater resources. In the event that these efforts are unsuccessful, the Commissioner has the authority, after reviewing all of the data, to declare an identified area as an Agricultural Management Area (AMA). An Agricultural Management Plan (AMP) could then be imposed that would require restrictions and limitations regarding the use of agricultural chemicals and/or require the implementation of BMPs within the effected area (AMA).
The intent of this document however, is to provide the necessary background and details regarding the design and implementation of the Monitoring Program. The following sections will describe the methodology utilized by the Program to identify, locate, and prioritize sampling locations throughout the State's principal agricultural areas. Section II is a summary of the various sampling

approaches that the Program utilizes. A summary of the historical sampling conducted by the Program, and the corresponding status of groundwater quality is provided in Section III. An overview of the Program's various aquifer sensitivity and vulnerability studies, as well as a synopsis of pesticide and fertilizer use throughout the State is contained in Section IV. The rationale and decision matrix utilized by the Program to prioritize areas for monitoring are presented in Section V. Proposed monitoring frequency is described in Section VI.

II. Historical Approach of the Groundwater Monitoring Program

The Monitoring Program was initiated in 1992, and has been collecting data on groundwater quality annually since that time. During this period, six regional surveys have been completed that covered the major agricultural areas of the State, as well as the urbanized Front Range corridor. Typically, the Program attempts to conduct one of these regional surveys every year. Summaries of these regional surveys are described in greater detail in Section III. Three of the State's major agricultural areas have been sampled multiple times, the South Platte River alluvial aquifer, San Luis Valley, and Arkansas River alluvial aquifer. One result of the Program's regional surveys has been the establishment of a long term monitoring project within the South Platte River alluvial aquifer in Weld County.

In addition to groundwater sampling, the Program also monitors pesticide and fertilizer use and associated cropping practices. These types of data are instrumental in determining the types and amounts of pesticides commonly used in Colorado's agricultural areas. For example, the USGS found that the use of glyphosate tripled between the years 1997 and 2001, but that alachlor, cyanazine, and metolachlor usage decreased over the same period (Scribner et al., 2003). Identifying changes such as these allow the Program to modify the annual monitoring efforts to reflect changing agricultural practices.

The Program has historically utilized different approaches to monitoring depending on current needs and objectives. In the early years, when little or no data on agricultural chemicals in groundwater existed, the Monitoring Program focused on acquiring baseline data from the major agricultural areas of the State. These baseline investigations often covered broad areas with relatively coarse sampling densities. Other factors that were considered during these baseline monitoring efforts included existing knowledge and distribution of both pesticide use and cropping practices.

As the Program's monitoring goals have evolved, the Monitoring Plan has been modified to address specific needs. These needs vary based on the location, amount of baseline data, agricultural practices, and the resource and budget constraints of the Program. In general, the Monitoring Plan will be based upon one of four possible monitoring approaches. These approaches include: reconnaissance surveys, regional monitoring, sub-regional monitoring, and dedicated monitoring networks.

Reconnaissance Surveys

Reconnaissance surveys are conducted to produce a brief assessment of groundwater quality in an area of interest to decide whether additional investigation is warranted. Usually between ten and 30 wells are selected for sampling. The wells used in a reconnaissance survey are typically existing domestic, irrigation, or monitoring wells. When possible the well locations are selected randomly, but often access and consent to sample by the well owner dictate the final locations. In some instances, when a specific problem is suspected, the well locations may be targeted in order to obtain the required information. In cases, when the results of a regional or sub-regional monitoring have identified anomalous results, a follow-up effort using a reconnaissance survey approach may be initiated in order to confirm inconsistent results.

Regional Monitoring

Regional monitoring involves collecting groundwater quality samples from approximately 100 wells throughout a particular region. Exact numbers and sample density varies according to the hydrogeology, geography, agricultural practices, and population density of the area. Typically the region consists of a river drainage basin and its associated alluvial aquifers or a major regional aquifer.

Sub-regional Monitoring

Sub-regional monitoring covers a smaller area, typically a tributary basin or a political sub-division such as county or a special district. The sampling goal usually ranges from 30 to 50 wells. The wells used in a sub-regional monitoring effort are often a function of where existing wells are located and the Program's ability to obtain permission to sample those wells. Sub-regional monitoring may also be used for confirmation sampling in the year following a regional monitoring event.

Dedicated Monitoring Networks

One key objective of any groundwater monitoring effort is the ability to assess water quality trends in the data (EPA, 1991). Dedicated monitoring networks represent one method of providing such information (EPA, 1997). The Program is planning to increase the number of dedicated monitoring wells available for its use by initiating a drilling program, with an annual budget of approximately $15,000. Although additional considerations such as cost are generated by the increased utilization of dedicated monitoring networks, the benefits include greater control over both the design and construction of monitoring wells, reduced problems with access, and greater probability of repeatable long-term monitoring. The location and number of wells installed will be determined by the hydrogeologic conditions and data needs of the Program.

The first dedicated monitoring network that the Program established was within the South Platte River alluvial aquifer between Brighton and Greeley (Weld County Network or Upper South Platte Network). This network was established in 1995, and originally consisted of a total of 92 wells. The network is composed of a combination of three well types that were selected to sample various depths within the aquifer. Of the original wells, 20 were dedicated monitoring wells screened in the top ten feet of the aquifer, 58 were irrigation wells that fully penetrate the aquifer, and 14 were domestic wells that typically sample from near the bottom of the aquifer. Over the years, the numbers of wells have varied slightly depending upon available access, changes in irrigation practices, and urban encroachment. Historically the Program has sampled irrigation and monitoring wells annually and the domestic wells every three years. Beginning in 2006, the Program will sample all three well types on an annual basis.

In 2004, utilizing a grant from the U.S. Environmental Protection Agency (EPA), the Program installed a second dedicated monitoring network within the Arkansas

River alluvial aquifer. This network is comprised of 20 monitoring wells that are located between the eastern edge of Pueblo County and the town of Holly, near the Colorado - Kansas border. The locations of the wells were selected based upon favorable hydrogeologic conditions (Weist et al., 1965; Beottcher, 1964, Voegeli and Hershey, 1965), proximity to existing agriculture, and access permission from landowners. These monitoring wells were shallow, with an installed depth of between 23 and 40 feet below ground surface. All wells were screened across the water table, with between 15 and 20 feet of screen. These wells were designed and installed to assess occurrences of agricultural chemicals within the Arkansas River alluvial aquifer.   The establishment of this dedicated monitoring well network will allow the Program to monitor long-term variations in the groundwater quality in this portion of the State, which is currently experiencing a number of challenges regarding the amount of available irrigation water. As the agricultural industry adapts to meet these challenges, this monitoring well network will be in place to assess potential changes that may occur in the groundwater quality.

III. Summary of Results for Areas Sampled by the Program

The Program has collected groundwater quality data in Colorado since 1992. Over 1,844 samples from 1,024 wells have been collected and analyzed for pesticides, nitrate, basic ions, and dissolved metals (Figure 1) as of 2005.

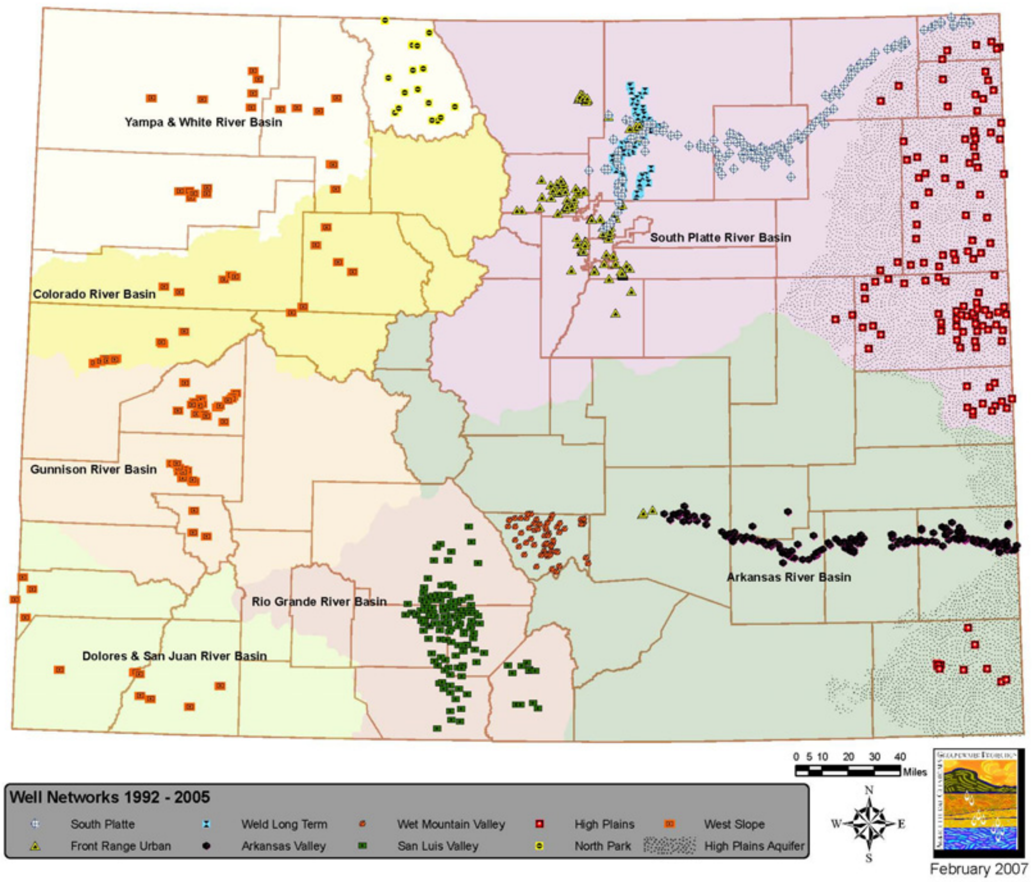

Figure 1. Location of Wells Sampled by the Agricultural Chemicals and Groundwater Protection Program in Colorado, 1992 – 2005.

The majority of groundwater monitoring to date has concentrated on the major agricultural regions of Colorado. In the early years of the Monitoring Program, areas and wells selected for monitoring were based on a combination of land use and hydrogeologic factors. Important land-use factors included; significant agricultural chemical use in the area, an absence of any identified point sources of contamination, and the presence of irrigation. Priority was given to shallow alluvial aquifers in the vicinity of major agricultural land use, as these typically represent those areas most susceptible to contamination. The wells selected for monitoring were based on a combination of factors, but priority was given to domestic use classification, depth to water less than 50 feet, and wellhead condition. Existing domestic, stock, and irrigation wells were selected for monitoring when available to minimize cost and meet sampling schedules. The potential problems associated with using these types of existing wells are well known (e.g. lack of data on the screened interval, very large screened intervals, inconsistent or incomplete hydrogeologic data, and poor wellhead protection and/or maintenance). However, proper planning combined with careful well selection can minimize these problems.

Figure 2 represents a summary of nitrate as nitrogen (NO_3-N) analytical results that were measured at or above 10 mg/L (the EPA drinking water standard) over the thirteen-year period 1992 - 2005. Based on the results of the nitrate concentrations, four areas of high nitrate concentrations are evident; the South Platte River alluvial aquifer, the Arkansas River alluvial aquifer, the San Luis Valley unconfined aquifer, and the High Plains aquifer.

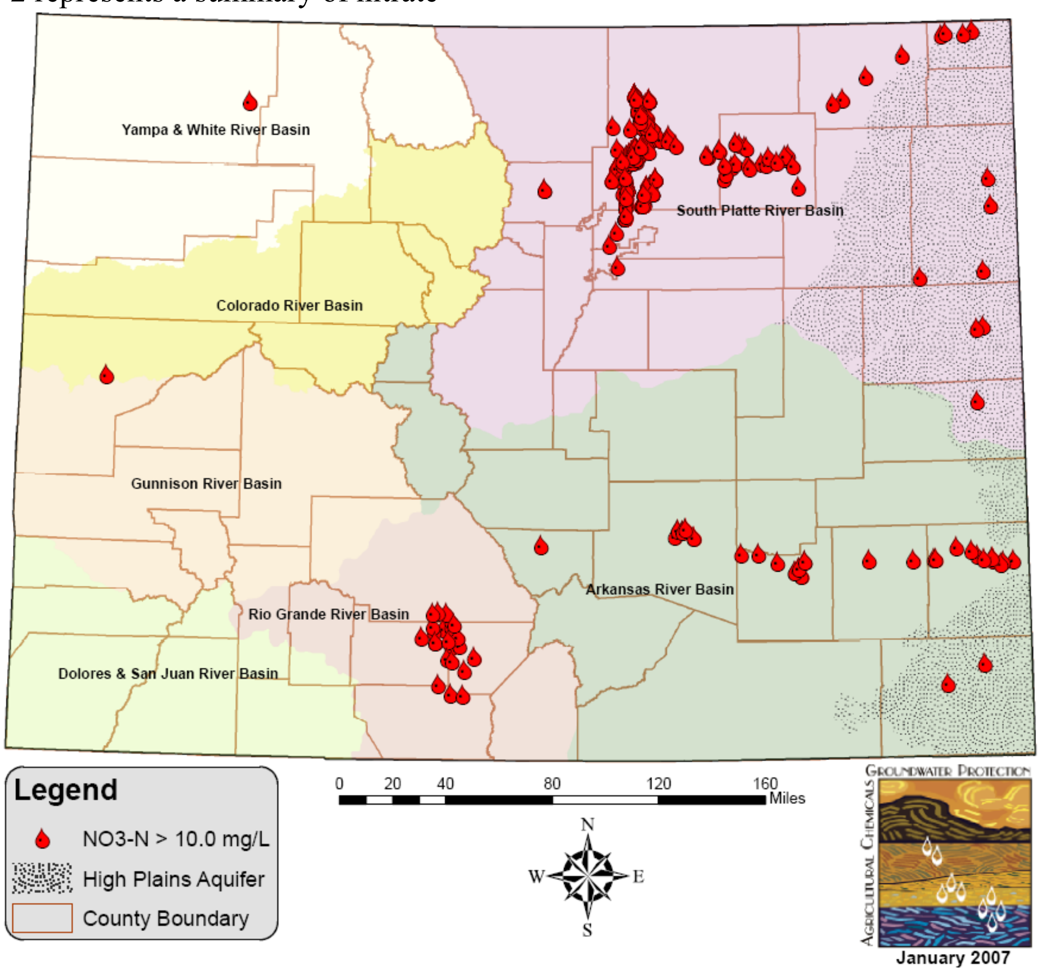

Figure 2. Location of Wells with Nitrate as Nitrogen (NO_3-N) at a Level of 10 mg/L or Greater, Based on Groundwater Sampling Between 1992 – 2005.

Of the approximately 1,000 wells sampled for nitrate during this period, about 23% (approximately 228 wells) had results that exceeded the drinking water standard for nitrate of 10 mg/L. One artifact of the nitrate data is that once sampling results from an area has indicated high nitrate concentrations, the Program revisits the area for additional investigation. This process results in repeated samples from areas where nitrate exceedances are expected, skewing the overall data distribution with results greater than 10 mg/L.

The majority of the nitrate exceedances occurred in the South Platte River alluvial aquifer, with the second most being observed from the San Luis Valley unconfined aquifer. These results were not unexpected, as these two regions historically have had intense agricultural activity and overlie major shallow groundwater aquifers. The aquifer sensitivity map (described in Section IV) also indicates that both of theses areas rank from moderate to highly sensitive to contamination from nitrate.

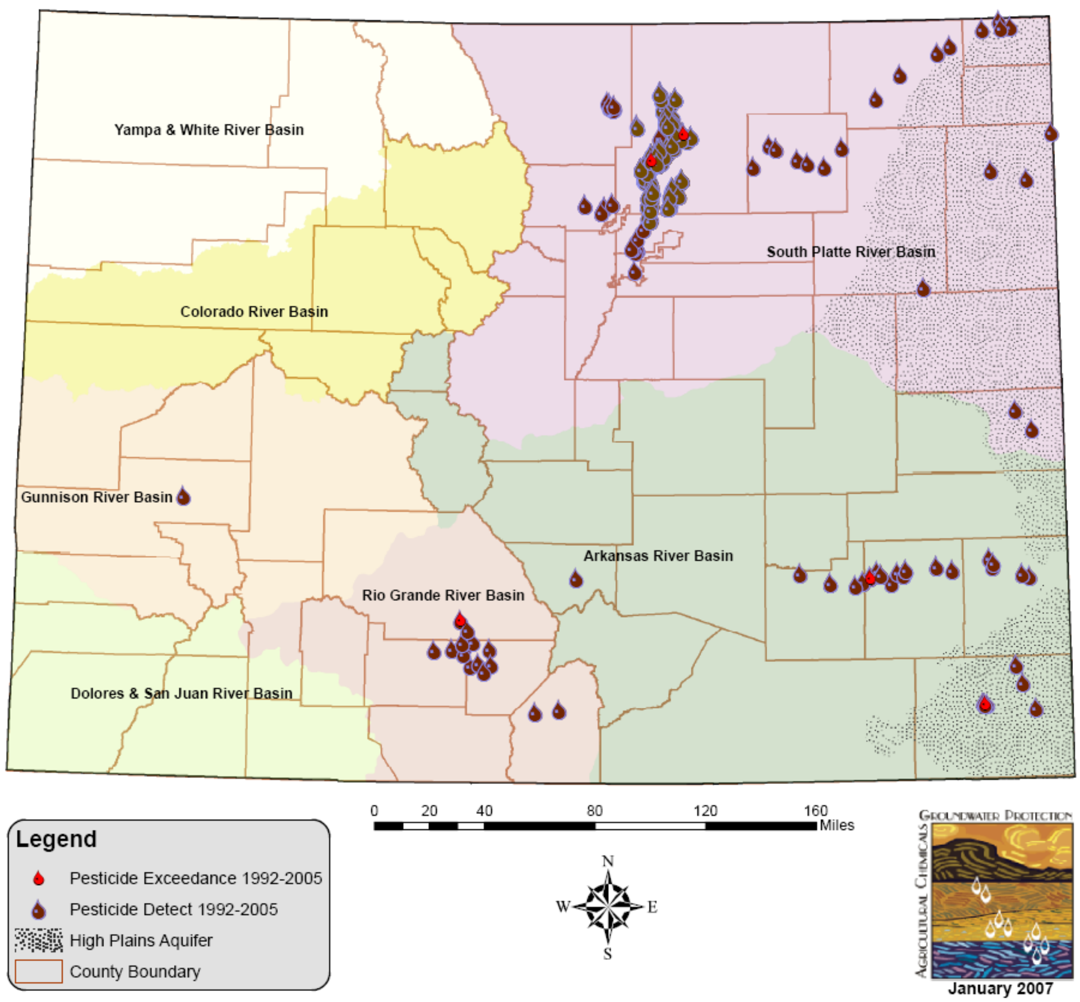

Figure 3. Locations of Samples with Pesticide Detections and/or in Exceedance of Drinking Water Standards for Wells Sampled from 1992 – 2005.

Wells testing positive for a pesticide at any level are shown in Figure 3. A total of approximately 120 wells (approximately 12% of the wells) had at least one pesticide present. As with the nitrate data, the pesticide data is also skewed due to multiple sampling events in areas where pesticides have been historically detected. The majority of pesticide detections in Colorado have been the herbicide Atrazine or one of its breakdown products Desethyl Atrazine or Deisopropyl Atrazine. The second and third most commonly detected pesticides are the herbicides Prometon and Metolachlor, respectively. The majority of pesticide detections occurred in the 0.1 to 1.0 µg/L (parts-per-billion, ppb) range, which would be below any associated drinking water standards or Health Advisory Levels. However, in five of the wells tested (<0.04%), the concentration of pesticide observed exceeded an established standard or drinking water limit.

As is the case with nitrate exceedances, the South Platte River alluvial aquifer accounted for the majority of pesticide detections. The second largest number of pesticide detections was observed in the Arkansas River alluvial aquifer. The San Luis Valley unconfined aquifer, and the High Plains aquifer also had multiple detections. In both cases, the majority of the levels were low (less than 1.0 ppb).

South Platte River Basin, Northeast Colorado

The South Platte River Basin alluvial aquifer system, which begins near Denver and follows the river valley to Julesburg, underlies the major agricultural region, in terms of acres of high value crops and livestock production, in Colorado. The area includes the South Platte River valley from the northern part of Denver County, to the Colorado - Nebraska border in Sedgwick County and includes numerous tributary stream valleys. Overall the area is approximately 200 miles in length and occupies about 1250 square miles.

The agricultural economy of the South Platte River basin is based on irrigated and dry land farming, as well as livestock production. The irrigated agriculture in this region is characterized by both surface water diversions and irrigation wells within the shallow unconfined aquifer. Because shortages of surface water occur during years of low runoff, and the timing of runoff often does not coincide with irrigation requirements, irrigation wells have been drilled in the valley to supplement to surface-water supplies. In some areas, groundwater pumped from wells is the sole source of water for irrigation. The majority of the towns and some industries in the area also obtain their drinking water from wells. Although nearly all the large-capacity wells are in the valleys, small-capacity domestic and stock wells have been constructed both in the valleys and on the uplands since early settlement of the region.

The alluvium in the South Platte River valley and its major tributaries was deposited in a channel eroded into the underlying bedrock and consists mainly of heterogeneous mixtures of clay, sand, and gravel, or lenses of these materials. The thickness of the alluvium ranges from less than a foot to more than 290 feet in some areas. Throughout the South Platte River valley and its tributary valleys, these deposits form an almost continuous unconfined aquifer that is in hydraulic connection (tributary) with the South Platte River. The valley-fill aquifer is recharged by precipitation, applied irrigation water, and leakage from canals and reservoirs.

The Program conducted a baseline regional monitoring effort for the South Platte River alluvial aquifer in 1992. This baseline regional monitoring consisted of 96 domestic wells within the alluvial aquifer, which were located between Denver and Julesburg. A confirmation reconnaissance survey was conducted in 1993 in Morgan and Sedgwick counties. In Morgan County, 17 wells that had been sampled in 1992 were resampled, and 17 additional wells were sampled for the first time. In Sedgwick County, eight wells were resampled, with an additional five wells sampled for the first time. In both cases, the additional wells were selected to further refine on a sub-regional basis, potential sources of nitrates in this area. Beginning in 1995, the Program initiated a long-term dedicated monitoring well network within the South Platte River alluvial aquifer between Denver and Greeley. Until 2006 the monitoring Program has sampled the monitoring and irrigation wells annually and the domestic wells every three years. Beginning in 2006, all wells have been sampled annually.

In addition to sampling the dedicated monitoring network in Weld County in 2001, the Program also sampled the alluvium along the lower South Platte River (Morgan, Logan, and Sedgwick Counties). This 2001 sampling effort included a total of 37 monitoring wells. Approximately one-half (19 wells) had nitrate concentrations greater than the 10 mg/L drinking water limit, and 62% (23) of the wells had detections of at least one pesticide.

Arkansas River Basin, Southeast Colorado

The Arkansas River Valley, downstream of Pueblo, is also one of Colorado's major agricultural regions. This region is characterized by intense irrigated agriculture encompassing both surface water diversions and wells for irrigation water supplies. The wells supply primarily surface water irrigation systems from the shallow unconfined aquifer. Supplemented by water supplied through trans-mountain diversions, the river and alluvial aquifer supply all of the water used for irrigation and a significant portion of the domestic supply for the area. The area includes the Arkansas River valley from just east of Pueblo to the Colorado - Kansas border in Prowers County. The area is approximately 150 miles in length and occupies about 400 square miles.

In the Arkansas River valley, surface water and groundwater are two components of the overall hydrologic system. The valley-fill aquifer is recharged by precipitation, applied irrigation water, and leakage from canals and reservoirs. Recharge to the aquifer from irrigated land has been estimated to be between 45 to 50 percent of the applied irrigation water and precipitation.

The alluvium in the Arkansas River valley was deposited in a channel eroded into the underlying bedrock and consists mainly of heterogeneous mixtures of clay, sand, and gravel, or lenses of these materials. Throughout the Arkansas River valley and its tributary valleys, these deposits form an almost continuous unconfined aquifer that is generally in hydraulic connection with the Arkansas River. Supplemented by water supplied through trans-mountain diversions, the river and alluvial aquifer supply the vast majority of the water used for irrigation and a significant portion of the domestic supply for the area. Groundwater return flows that augment the flow of the river are the direct result of recharge from applied irrigation water and precipitation. As a result of consumptive losses, due to evaporation and evapotranspiration, recharged groundwater tends to be higher in dissolved solids than the applied irrigation water. This creates a general increase in dissolved solids concentration in a down-gradient and down-valley direction within the alluvial aquifer. This phenomenon is not unique to the Arkansas River valley, and is typical of areas where irrigation return flows comprise the majority of the groundwater recharge.

A baseline regional sampling effort was conducted along the Arkansas River in 1994. This regional baseline monitoring effort included 146 domestic, stock, and irrigation wells that were located between Pueblo and the Colorado - Kansas state line. In 1995, a reconnaissance survey was conducted on 32 wells that had either pesticide detections or a nitrate concentration exceeding 10 mg/L during the 1994 regional sampling event.

The Arkansas River alluvial aquifer, one of the four areas of concern identified by both historical nitrate and pesticide results, lacked any type of monitoring well coverage. In 2004, the Program installed 20 dedicated monitoring wells with a grant from the EPA. Nitrogen analysis indicated that only one of the 19 wells sampled (5%) showed nitrate levels in excess of the EPA standard for drinking water (10 mg/L). One well tested below the laboratory detection limit of 0.1 mg/L. The remaining 17 wells (89%) tested positive for nitrate but were below the EPA standard. Pesticide data revealed three pesticides, Atrazine, Metolachlor, and 2,4-D present in the groundwater samples. The breakdown product of Atrazine, Deethyl Atrazine, was also present in a sample from one well. No pesticide concentration exceeded any applicable water quality standard or health advisory.

In 2005, in conjunction with the Colorado Department of Public Health and Environment, the Program again sampled the dedicated Arkansas alluvial aquifer monitoring well network. Target analytes for the 2005 sampling effort included nitrate, pesticides, selenium, and select metals and ions. Nitrate analytical results indicated that only one of wells had a nitrate concentration (13.7 mg/L) greater than the drinking water limit of 10 mg/L. Pesticide analytical results indicated a single detection of Metolachlor at 0.59 µg/L, as well as a single detection of Deethyl Atrazine (0.79 µg/L), the breakdown product of Atrazine.

San Luis Valley, Rio Grande Basin Colorado

The San Luis Valley is characterized by intense irrigated agriculture encompassing both surface water diversions and wells for irrigation water supplies. The wells supply surface and center-pivot irrigation systems from the shallow unconfined aquifer and deeper confined aquifer. The San Luis Valley of south-central Colorado is an intermontane valley bounded by the steep Sangre de Cristo Range to the east, and on the west by the San Juan Mountains. The valley is about 115 miles long, and exhibits a maximum width of about 50 miles near Del Norte, Colorado. Overall the San Luis Valley covers an area of approximately 3,200 square miles (over two million acres).

The two major hydrologic regions in the San Luis Valley that could potentially be impacted by agricultural chemical use include the closed basin and the Rio Grande River drainage basin. Unconfined groundwater underlies the entire San Luis Valley, generally at depths of less than 20 feet. Most of this groundwater occurs in the upper part of the Alamosa formation above the first confining layer. The principal factors that control groundwater levels in the San Luis Valley are recharge from infiltration of irrigation water, recharge from precipitation, recharge from artesian aquifers, and discharge by evapotranspiration, discharge into streams and drains, and discharge from wells.

The majority of the San Luis Valley's economy is based on agriculture. This agriculture consists of irrigated farming and livestock production. Due to the arid climate and high altitude of the valley, the principal irrigated crops are alfalfa, potatoes, barley, wheat, spinach, and lettuce. Pasture on native grasses is the principal dry land use. The farming enterprises in the San Luis Valley can be divided into three basic types: potato and small grain (mostly barley) rotations under center pivot irrigation, vegetable producers who rotate with hay or small grains under center pivot or furrow irrigation, and general livestock in the areas with native meadow hay sustained by a shallow water table. A large portion of the eastern side of the valley is rangeland or wasteland due to the poor soil conditions.

In 1993, the Program conducted a regional baseline investigation in the San Luis Valley. This monitoring effort included 93 domestic wells within the unconfined alluvial aquifer that were located throughout the valley. Nitrate analysis indicated that 13 out of 90 samples analyzed (14%) exceeded the drinking water standard of 10 mg/L. Only three pesticides were detected, but one result for Lindane exceeded the drinking water standard of 0.2 μg/L.

In 2000, the Program conducted sub-regional monitoring in the San Luis Valley. The Program, in conjunction with the USGS National Water-Quality Assessment (NAWQA) program, sampled 33 monitoring wells throughout the San Luis Valley. The results of this sampling event were used for verification of the aquifer vulnerability investigation.

High Plains, Eastern Colorado

The High Plains, or Ogallala Aquifer, is the principal aquifer within the High Plains Region of Colorado and is part of the largest aquifer system in the United States. The Ogallala aquifer underlies an area of about 12,000 square miles and is the primary source of domestic and irrigation water for residents. The Ogallala aquifer is a poorly consolidated sand and gravel deposit that was eroded from the Rocky Mountains and deposited on an erosional surface sloping gently eastward away from the mountain front. The Ogallala and other Tertiary formations form the extensive High Plains aquifer. Paleozoic sedimentary rocks underlie the Ogallala Formation in eastern Colorado, but generally these bedrock aquifers are not extensively used for domestic or irrigation wells. The saturated thickness in the Ogallala ranges from as little as ten feet along the western boundary of the High Plains to 340 feet in northeastern Yuma County. Depth to groundwater in the Ogallala formation can range from 50 feet along the western edge of the aquifer to over 150 along the eastern boundary of Colorado.

Colorado's High Plains region includes most of the State east of the Rocky Mountain foothills, but excludes the valleys of the South Platte and Arkansas rivers. The High Plains includes all or part of 11 counties and comprises an area of about 9,500 square miles. The Colorado portion of the aquifer is bounded by the State line on the east, the South Platte River on the north, Big Sandy Creek on the west, and the Arkansas River on the south. South of the Arkansas River, a small portion of the High Plains exists in Prowers, Baca and Bent counties.

Agriculture is the basis for the economy in much of the High Plains, and irrigation is necessary in most years for certain crops and in some years for all crops. Use of groundwater for irrigation plays a major role in the agricultural economy of the High Plains with the total number of irrigated acres exceeding 600,000, or approximately 17% of all irrigated cropland in Colorado.

A reconnaissance monitoring of the High Plains aquifer was conducted by the Colorado Department of Public Health and Environment in 1989 utilizing 23 irrigation wells within Yuma County. Analytical results from this sampling event found four Atrazine detections, and the maximum nitrate concentration observed was 11.3 mg/L. Regional baseline monitoring of the Ogallala Aquifer was conducted in 1997. Sampling included 129 wells, with the majority of the wells located between the South Platte and Arkansas Rivers in the eastern portion of Colorado (Figure 1). Additional wells were located south of the Arkansas River in the general vicinity of the town of Springfield. All wells sampled had nitrate detections, but only eight wells (6%) had concentrations of nitrate greater than 10 mg/L. Atrazine, its breakdown product Deethyl Atrazine, Prometon, and Bromacil, were detected in nine of the 129 wells (7%). In one well, an Atrazine concentration of 3.9 µg/L was observed, which exceeded the drinking water standard of 3.0 µg/L.

Front Range Urban Corridor

The Front Range urban corridor represents a mostly non-agricultural area that the Program first sampled in 1996 using a regional monitoring approach. The urban uses of pesticides and fertilizers include commercial and homeowner applications to landscapes, and municipal and private applications to parks, golf courses, green belts, as well as past agricultural applications. The largest segment of licensed commercial pesticide applicators is located within the urban Front Range corridor.

In the 1996 baseline monitoring, 72 existing wells were sampled for nitrate and 46 wells were sampled for the presence of pesticides. The majority of these wells were private domestic wells, but nine monitoring wells within the municipal boundaries of several cities and towns along the South Platte. These wells were located mainly east of Interstate 25, and were considered representative of recently converted agricultural areas to urban subdivisions. The nitrate results indicated that 10% of the sampled wells exceeded the nitrate drinking water standard of 10 mg/L. However, the Weld County monitoring wells represented the vast majority of the wells with nitrate concentrations above the standard. When the nitrate results fro the monitoring wells are excluded from the analysis, the percentage of wells exceeding the standard decreases to 5%. Pesticide detections included: Atrazine, Deethyl atrazine, Bromacil, and Prometon. There was no observable trend in the pesticide detections, with no apparent preferential detections associated with the monitoring wells. All of the pesticide detections were at levels below any corresponding drinking water standard or health advisory.

Beginning in 2005, the Program initiated a second regional monitoring effort of the Front Range Urban Corridor. The intent of this monitoring is to increase the amount of baseline data for further assessment of potential impacts due to urban uses of pesticides and fertilizers. This phase of regional monitoring is designed to assess areas that have a long history of urban land use. Therefore, the Program intends to locate the majority of these wells within the metropolitan areas of the major Front Range cities from Fort Collins to Pueblo.

The development density of this area creates special considerations for monitoring, due to the limited availability of existing domestic and irrigation wells. However, there are currently hundreds of dedicated monitoring wells throughout the metropolitan area that have been used for other purposes unrelated to agricultural chemicals. The Program is currently working on establishing a monitoring network from these existing monitoring wells.

During 2005, the Program initiated Phase I of this regional monitoring effort that focused on identifying suitable monitoring wells, and then securing access from the respective owners. The Program selected and sampled 40 existing monitoring wells that included 35 located within the Denver-metropolitan area. The remaining five wells were located in both Greeley and Windsor. Of the 40 wells sampled for nitrate, five had concentrations in excess of the drinking water standard of 10 mg/L. However, samples from eight wells were below the detection level for nitrate. Three wells had detections of MCPP, a pesticide similar to 2,4-D, all of which were slightly, ranging from 0.040 to 0.043 μg/L, above the laboratory detection limit of 0.03 μg/L. Additional sampling of the final network of monitoring wells is currently planned and will take place under Phase II that will include additional Front Range Municipalities.

West Slope, Western Colorado

Colorado's West Slope region includes all of the State west of the Continental Divide of the Rocky Mountains. The Western Slope in Colorado comprises an area over 38,000 square miles. This area ranges in altitudes from 7,000 feet in the valleys to over 14,000 feet for the highest mountains. The mountain ranges are composed of a mixture of igneous, metamorphic, and sedimentary rocks. The majority of precipitation, which can range up to approximately 40 inches per year, occurs in the form of winter snow pack. This snowfall then melts in late spring to recharge the alluvial aquifers that bound the major stream valleys. The majority of the groundwater sampled on the west slope occurs in these alluvial deposits along stream and river valleys, with some non-alluvial aquifers associated with the larger mesas. The dominant land use in this region is forest and rangeland.

Agriculture was the original foundation for the economy in this region and still comprises the largest land use. The majority of the agriculture in the region is rangeland or pasture with hay as the major crop. The agriculture in this region is predominately ranching with associated hay production, but other crops include irrigated wheat, corn, beans, as well as fruit orchards and vineyards.

Groundwater has not been extensively developed in the majority of the area, as most incorporated municipalities rely on surface water. But in the rural areas, groundwater from private wells is the major source for domestic water supplies. The majority of this domestic use is derived from the more economical and productive wells located in alluvial aquifers. These alluvial aquifers consist of a mixture of boulders, gravel, sand, and silt with thickness ranging from 20 to over 100 feet.

In 1998, the Program completed a baseline regional monitoring effort on Colorado's western slope. This baseline-sampling event included 90 wells, which were primarily located in the alluvial aquifers adjacent to the region's major rivers. Nitrate results indicated that more than one-third (36%) of the wells had concentrations less than the laboratory detection limit of 0.05 mg/L, and only one well had a nitrate concentration that exceeded 10 mg/L. Only one pesticide, Malathion, was detected at a concentration of 0.23 μg/L.

The Tri-River region on the west slope of Colorado is an area of interest to the Program. Centered in the vicinity of Delta, this area represents one of the larger agricultural areas of the west slope with a number of non-hay crops being produced. The Program currently has long-term plans to increase the sampling density of this area by incorporating additional wells. This area is also a candidate to receive a dedicated monitoring well network since the number and locations of domestic and irrigation wells currently restricts the Program's ability to adequately conduct a regional baseline monitoring.

Additional Program Groundwater Quality Monitoring

In 2000, the Program conducted sub-regional monitoring in the North Park area of Jackson County. A total of 21 domestic wells in the area were sampled, and no pesticide detections where found. The nitrate results indicated that all of the samples had concentrations less than the drinking water limit of 10 mg/L, and 20 wells (95%) had a concentration less than 5 mg/L.

A sub-regional monitoring effort was also conducted in Custer County during 2002. This sampling effort included 58 domestic wells within the Wet Mountain Valley. The majority of the wells (69%) had nitrate concentrations below 2.5 mg/L, and only one well sampled had a nitrate concentration that exceeded the drinking water limit. Only one pesticide, Picloram, was detected in a single well, and the concentration was below the drinking water standard. The one pesticide detection was for Picloram but was well below the drinking water standard.

During 2005, in cooperation with Gilpin County Cooperative Extension, the Program conducted a sub-regional monitoring effort that included 37 domestic wells mainly located in the northeast portion of the county. This area of Gilpin County has mainly fractured bedrock aquifers, predominately granite, with minor alluvial aquifers along the local creeks and streams. Nitrate analytical results were all below the drinking water standard of 10 mg/L, and nine of the wells had non-detect nitrate concentrations. All the remaining nitrate concentrations were below 5 mg/L. None of the 37 wells had any detectable levels of pesticides.

Additional Sources of Groundwater Quality Data

Other agencies working in Colorado have collected groundwater quality data for their own needs, in response to public concern, or by Legislative direction. The Program's use and integration of these outside sources of data varies according to how, by whom, and for what purpose the data was collected. If the field and laboratory methods used by these external parties are found to be reliable, the data is then incorporated into our process of evaluation. Most recently, data from the USGS NAWQA program has been used in this manner.

IV. Monitoring Prioritization Factors

Today, the Program has the use of tools and data that were unavailable in the early years of the Program. These tools and data include such things as research on aquifer sensitivity, estimates on pesticide and fertilizer use, and current data on groundwater quality. The integration of these various components into a priority matrix can be utilized to determine Program monitoring priorities and select areas for future monitoring.

Aquifer Sensitivity and Vulnerability Models

Aquifer sensitivity and vulnerability models represent one method of determining potential areas within Colorado that may be susceptible to contamination from agricultural chemicals. These models combine a number of physical factors, including various weighting factors, to derive a score that is related to the potential for contamination. These scores can then be used to identify "high risk" areas that can be prioritized for monitoring on a more detailed basis.

Sensitivity, as defined by the EPA, means "the relative ease with which a contaminant (in this case a pesticide) applied on or near a land surface can migrate to the aquifer of interest. Aquifer sensitivity is a function of the intrinsic characteristics of the geologic materials in question, any overlying saturated materials, and the overlying unsaturated zone. Sensitivity is not dependent on agronomic practices or pesticide characteristics."

Vulnerability analysis is the process of combining information regarding the chemical properties of the chemical in question, the behavior of a particular chemical in the soil types of the region under study, the depth to groundwater, land use, and other factors in order to assess the potential of a specific chemical to contaminate groundwater.

Vulnerability therefore depends on both the characteristics of the pesticide as well as the physical hydrologic setting. Sensitivity is only based on hydrologic characteristics. For example, an area might be found to be highly vulnerable to atrazine, yet not very vulnerable to malathion due to such things as chemical differences and how they react in the environment. This same area would have the same level of sensitivity regardless of the pesticide.

The Program has collaborated on several Colorado specific aquifer sensitivity and vulnerability studies (Ceplecha, 2001; Ceplecha et al., 2004; Hall, 1998; Rupert, 2003; Schlosser et. al., 2002). These studies have considered both pesticides as well as nitrate, and have typically relied on regionally quantified factors to assess sensitivity and vulnerability throughout the State.

Four factors were consistently identified by these studies as critical in describing the sensitivity of groundwater to pesticide contamination in Colorado:

- Presence of alluvial or defined aquifers,
- Depth to water table,
- Permeability of materials overlying aquifers,

- Availability of recharge for transport of contaminants (i.e. flood and pivot irrigation).

These selected factors incorporate important aspects of Colorado's unique climate, hydrogeology, and agricultural setting.

Sensitivity and Vulnerability Assessment

An indicator, or surrogate, for each factor above was chosen for use in calculating the overall aquifer sensitivity. Other related factors may be included depending on the model. For the factors, GIS data layers were developed for each of the four indices described above, and then transferred to a regular grid. The resulting model yields a range of values, and for ease of interpretation, this range was rescaled to obtain a sensitivity index shown on the sensitivity map in Figure 4.

Sensitivity values range from areas that are not irrigated and/or do not overlie conductive aquifers, to highly sensitive areas where a very shallow water table in a highly conductive aquifer coincide with at least moderately permeable soils that receive irrigation.

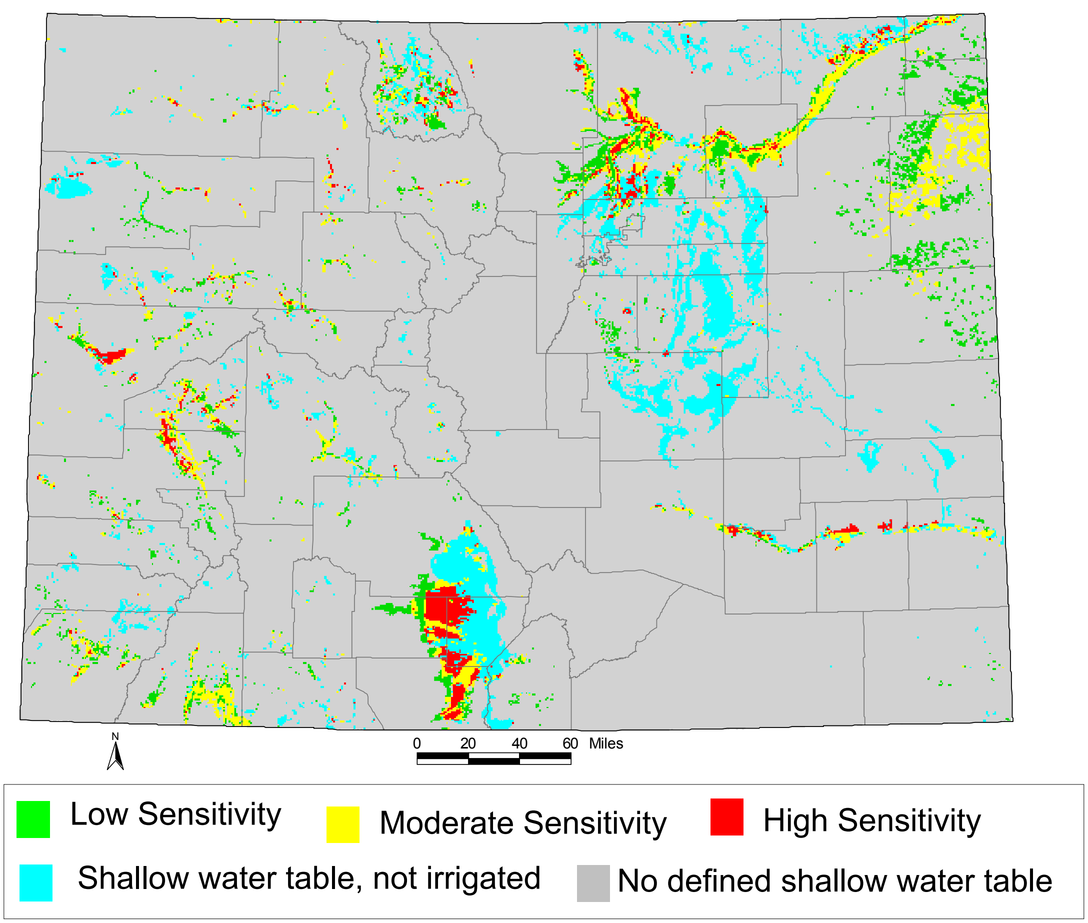

Figure 4. Aquifer Sensitivity to Pesticide Contamination in Colorado.

The sensitivity/vulnerability mapping projects are intended as general guides in identifying areas of the State in which groundwater, due to its hydrologic and geologic setting, is more or less susceptible to contamination from agricultural chemicals. Conceptually, the sensitivity and vulnerability models are intended for regional-scale assessments. Therefore, individual values produced by the model should not be considered absolute, but rather should be interpreted based on the values of surrounding results. For example, a single result from the model may be identified as highly sensitive due to a slightly shallower water table (just above the threshold criteria), yet be surrounded by moderately sensitive results. In cases such as this, the highly sensitive result should not be interpreted individually, but rather in conjunction with the surrounding cells. The sensitivity map should be used to support conclusions concerning regions on a minimum scale of tens of kilometers.

The Program has taken the framework of these sensitivity investigations and expanded their scope to assess agricultural chemical specific vulnerability. The first vulnerability investigation (Schlosser, et al., 2002) included a broad investigation of a number of pesticides based on their associated partitioning coefficients and environmental half-life (environmental fate). Other factors that were included were an estimate of the fractional organic content of the soil. Verification of this broad approach of including multiple pesticides included comparison of the Program's pesticide analytical data to those areas identified as highly vulnerable. The verification indicated that approximately 90% of the actual pesticide detections occurred within areas that were identified as highly vulnerable, yet very few pesticide detections occurred within areas identified with low vulnerability.

In 2003, the Program, in conjunction with the USGS (Rupert, 2003), developed a series of vulnerability maps, based on probabilities of detecting Atrazine, desethyl-atrazine, and nitrate in Colorado's groundwater. This investigation used a multivariate model that incorporated the various sensitivity factors in combination with land use information and estimates of the amount of applied agriculture chemicals to predict probabilities associated with finding atrazine, desethyl-atrazine, and nitrate in groundwater. These probabilities correlate with associated vulnerability in an area with high probability of detecting a particular compound and would represent an area that would be considered more vulnerable.

A nitrate specific vulnerability investigation was also completed in 2004 (Ceplecha, et al., 2004) for both statewide and field scale applications. A comparison of the Program's nitrate data to predicted statewide vulnerability indicates that both methodologies were able to predict areas of increased aquifer vulnerability. The field scale application was evaluated against three sources of field data and established that the method could be used to determine relative vulnerability for different field conditions. The investigation results indicate that both methods could be effectively applied in Colorado to predict nitrate vulnerability.

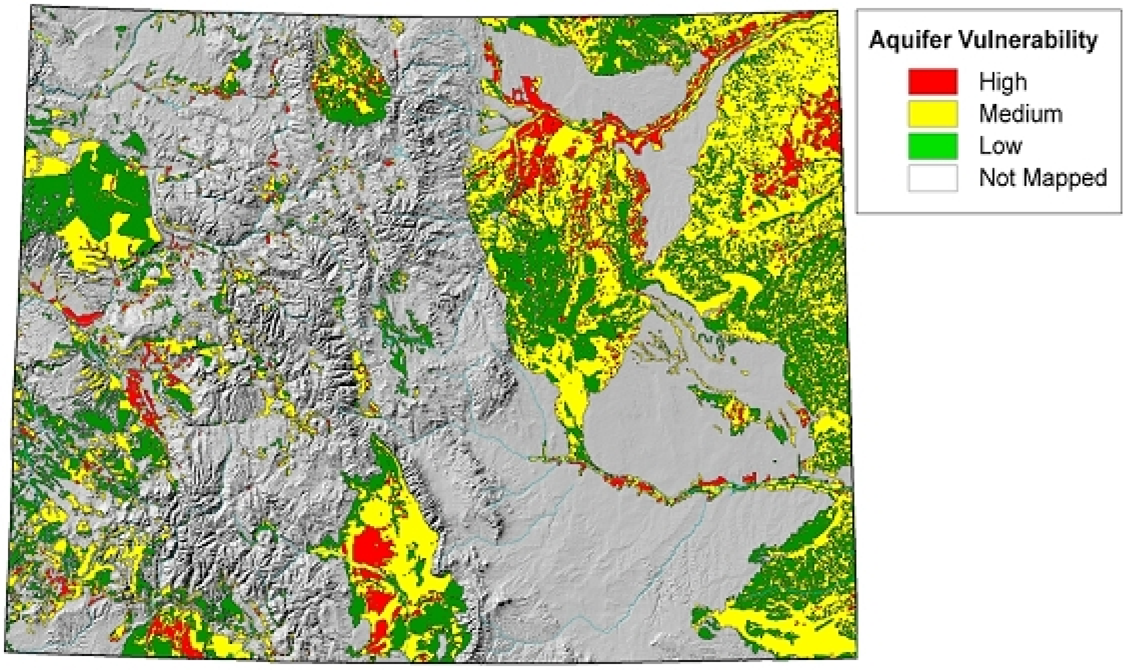

Figure 5. Vulnerability of Colorado Groundwater to Nitrate Contamination as Mapped by Ceplecha, 2004.

The sensitivity and vulnerability models can be used to identify those areas of the State that may be more susceptible to contamination from the improper use of agricultural chemicals. As can be shown in Figure 5, these areas tend to be associated with shallow alluvial aquifers. These aquifers, which typically have high yields, tend to be the aquifers that have been historically exploited for irrigation. Consequently, the most vulnerable areas are commonly associated with those areas that have historically represented the major agricultural areas of the Colorado.

Pesticide Use

The Program relies on pesticide use surveys to assess the types and distribution of the use of the common agricultural chemicals. For Colorado, the most recent survey (1997) indicates that 82.8 million ounces of pesticide were applied in Colorado (Matti, 2001). Agricultural related applications consisted of 51.2 million ounces (62%) of this total (Figure 6). The largest amount of pesticide, 24.3 million ounces, was applied to wood products. The second largest amount, 16.9 million ounces, was applied to corn crops. The third largest amount, 16.7 million ounces, was applied in other agricultural uses, the majority on other crops. The fourth and fifth largest amounts, 8.3 million and 6.8 million ounces, were applied to potatoes and winter wheat respectively. Colorado's commercial and private agricultural applicators treated 4.6 million acres with pesticides in 1997.

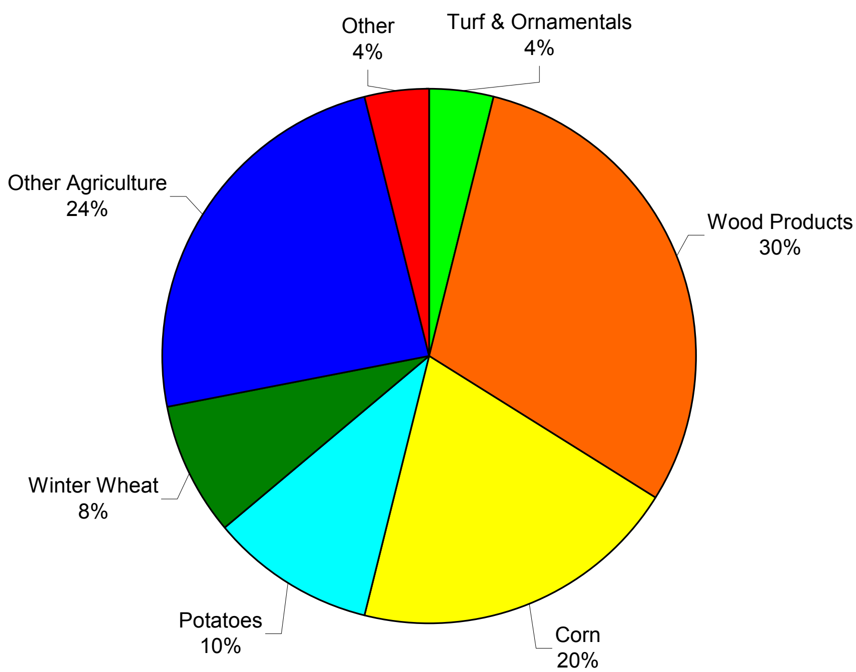

Figure 6. Pesticide Applications in Colorado 1997.

Adams County was reported to have the largest amount of chemicals applied, due to the large amount of wood products treated with creosote. The Front Range Region accounts for 44%, 36.3 million ounces, of the pesticide applied in the State, due largely to industrial uses in Adams County (Table 1).

Table 1 - Regional Totals of Pesticide Use in Colorado (1997)		
Region	**Total Ounces Applied (Millions)**	**Percent of Total**
Front Range	36.3	44%
Eastern Plains	20.1	24%
San Luis Valley	7.0	9%
Western Slope	3.5	4%
Central	0.04	0%
Private Applications[1]	15.8	19%
Unknown	0.01	0%
State Total	**82.8**	**100%**
1) Private agricultural applications were not assigned to a particular region because county data for these applications were not available.		

The Eastern Plains Region comes in second at 20.0 million ounces, or 24% of Colorado's pesticide applications. Weld and Yuma Counties (highly productive agricultural areas), were second and third to Adams County respectively, comprising 14%, or 11.5 million ounces, of the State's total amount of pesticide applied.

Figure seven represents a statewide summary of pesticide use that was normalized by area.

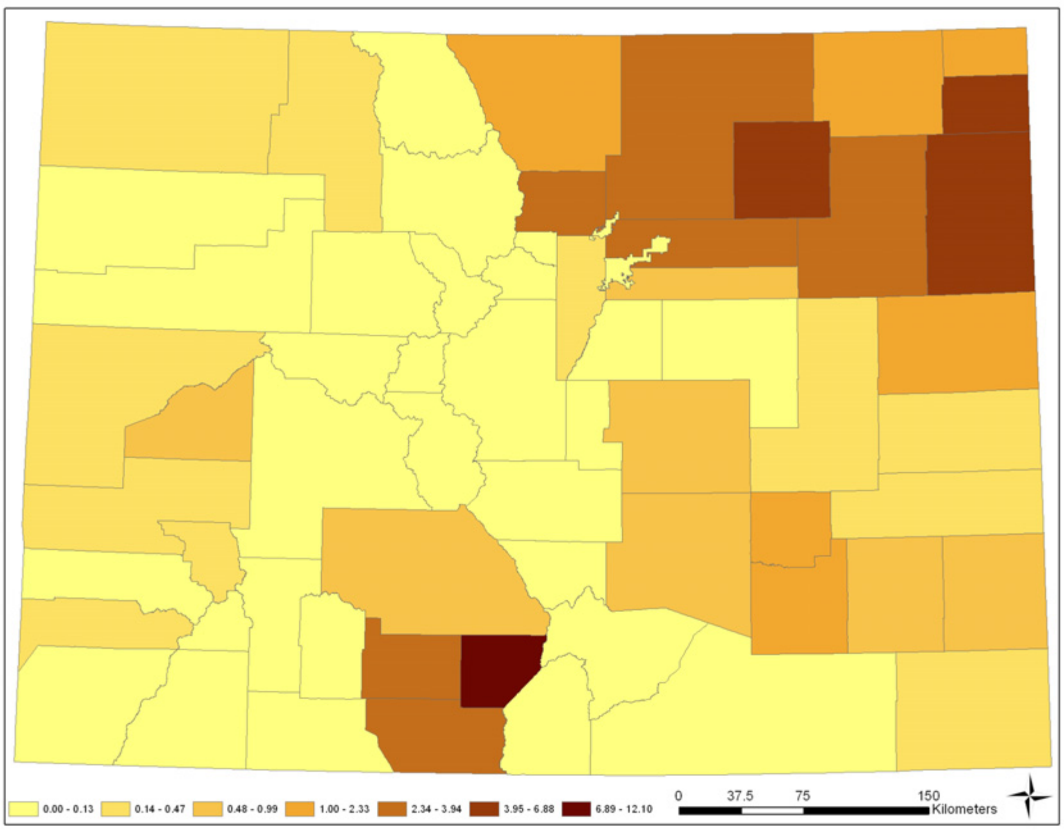

Figure 7. Normalized Pesticide Use by County in Pounds per Acre.

To derive this map, the Program took the total number of pounds applied within the county, and then normalized this value based on the total area in acres to derive an average application rate. This normalization was necessary to accurately estimate the amount of applied pesticide. Smaller counties could be underestimated if the map included only the total pounds of pesticide. On this map, the major agricultural areas within Colorado are quite evident, with the South Platte River basin, the Arkansas River Basin, the San Luis Valley, and Tri-rivers area all having larger per-acre estimates of pesticide application.

Fertilizer Use

County level estimates of fertilizer use in Colorado were based on the estimates that Ruddy et al. (2006) produced based on information obtained from the Association of American Plant Food Control Officials (AAPFCO). These estimates span the time period between 1982 and 2001, and included both farm and non-farm fertilizer inputs. To derive county-level application rates, the annual sales for States were aggregated and then apportioned to individual counties based on fertilized acreage data from the Census of Agriculture. To derive a representative value for fertilizer use, the Program averaged the annual county fertilizer inputs, for both farm and non-farm applications, from the most recent 10 years (1991 through 2001). The resulting averages were then normalized based on county area to arrive at an average application rate.

Figure eight is color coded to indicate the calculated fertilizer application rates for Colorado counties, with darker colors indicating higher average application rates. As expected, the key agricultural areas of the State are evident based on higher fertilizer application rates, with Yuma and Phillips Counties having the largest average annual rate of between 24 and 39 pounds per acres (lb/ac). Other counties that exhibited average annual application rates of between 9 and 24 lb/ac included Sedgwick, Kit Carson, Weld, Morgan, Alamosa, and Rio Grande Counties.

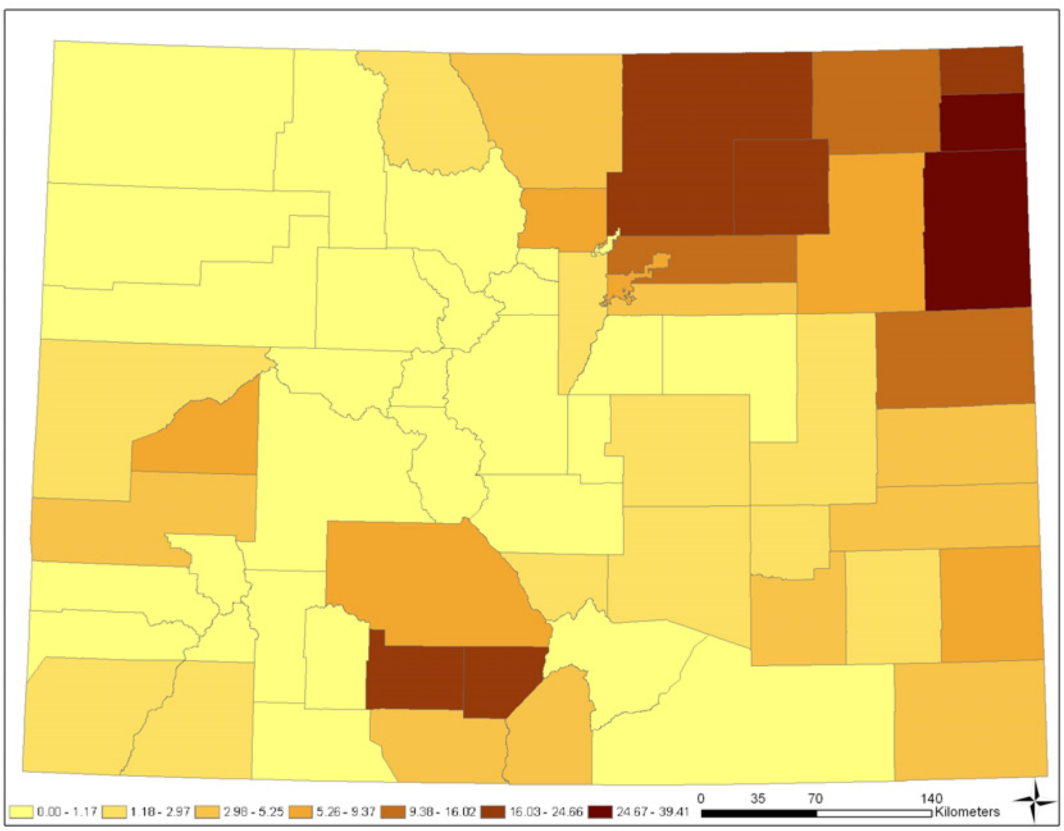

Figure 8. Normalized Nitrogen Use by County in Pounds per Acre.

Prioritization of Areas for Monitoring

Prioritization of the Program's sampling areas is a function of historical monitoring, sensitivity and vulnerability of associated aquifers, and the statewide distribution of pesticide use. In order to incorporate these factors into a long-term monitoring plan, the Program has developed a priority, or decision matrix. The objective of the priority matrix is to accurately identify those areas where agricultural chemicals have the potential of being found in groundwater. Then, active sampling and monitoring efforts can be directed such that potential impacts can be detected and addressed early, reducing the possibility of the need to declare an AMA. The matrix assigns a score based on the results of five criteria, which are then weighted depending upon the relative importance of each factor. The resulting total numeric score is then utilized to rank the various agriculture areas of the state in terms of monitoring priority.

The general criteria of historical monitoring, sensitivity and vulnerability of associated aquifers, and the statewide distribution of agricultural chemical use have been broken out into five criteria for which a numeric score can be assigned. These criteria include:

1. Nitrate Exceedance Levels (a function of baseline water quality),
2. Pesticide Detections (a function of baseline water quality),
3. Pesticide Use (a function of the statewide distribution of agricultural chemical use),
4. Fertilizer Use (a function of the statewide distribution of agricultural chemical use) and,
5. Sensitivity and vulnerability rankings for nitrate and pesticides (a function of the aquifer sensitivity and vulnerability).

Additionally, the priority ranking for areas with baseline water quality data is slightly different than areas that have not yet been sampled. This difference is due to the fact that a portion of the ranking criteria is based on water quality results, and in areas where monitoring has not occurred, there is no data available to include for these criteria. By ranking the un-sampled areas in this manner, the resulting priority score can more readily be compared to those areas where baseline water quality data already exists.

For each of the criteria, a score is derived and assigned for a particular area being considered for monitoring. These scores are then weighted, based on the magnitude of the raw score, and summed to arrive at a single total score. The higher the total score, the higher the priority that area would have with regard to the need for groundwater quality monitoring

Weighting factors vary between the criteria, with sensitivity ranking receiving the highest overall weight, and agricultural chemical use receiving the lowest. In this way, areas that have identified sensitive or vulnerable aquifers associated with significant use of agricultural chemicals receive a higher priority than aquifers with low sensitivity or vulnerability and general lack of agricultural chemical use. The following table (Table 2) contains the weighting factors, and the details regarding the raw scores are described in greater detail in the following sections.

Table 2 – Summary of Weighting Factors							
Scoring Criteria Weighting Factors	Nitrate Exceedance Levels[1]	Pesticide Detections[2]	Fertilizer Use	Pesticide Use	Nitrate Vulnerability	Pesticide Sensitivity	Total Weighting Factors
Sampled Region Weighting	2	2	1	1	3	3	12
Un-sampled Region Weighting	0	0	2	2	4	4	12

1) Nitrate concentrations above 10 mg/L.
2) Any pesticide detection above the laboratory minimum detection level.

The highest weightings were assigned to the sensitivity and vulnerability ranking criteria since monitoring sensitive aquifers is a critical prerequisite for early detection of potential contamination. An intermediate weighting factor was selected for pesticide detections and nitrate exceedances, as that would be indicative of potential existing impact due to agricultural chemicals. Pesticide and fertilizer use was assigned the lowest weighting factor. There are several reasons for this approach. First, use of these chemicals does not necessarily imply an impact to groundwater. Application per labeling requirements, as well as the implementation of BMPs, allow for the use of these chemicals in an environmentally responsible manner. Secondly, as described above, over 19% of all pesticide applications are conducted by private applicators, and data regarding application amounts and the counties of those applications is unavailable for consideration in the priority matrix. Additionally, the results are based on a survey of applicators, and are indicative, but not definitive, regarding the status of pesticide and fertilizer use. For these reasons, pesticide and fertilizer use, though an indicator of potential impacts, were not weighted as heavily as the other criteria.

However, this weighting factor philosophy does not apply in un-sampled regions, where without any existing groundwater quality data; there is no data available to quantitatively assess existing impacts to groundwater. Therefore, for un-sampled regions a slightly higher weighting factor is used for pesticide and fertilizer use. These higher weighting factors, which also were increased for aquifer sensitivity, were deemed appropriate for those areas where no water quality data is available. For both the sampled and un-sampled areas, the total value of the weighting factors was twelve, with the intent that the weighting factors would not introduce a bias between the two types of regions.

Nitrate Exceedance Levels and Pesticide Detections

For sampled areas, one of the criteria for determining the final priority score includes an assessment of the existing water quality with respect to the presence of agricultural chemicals. These criteria are fundamental to one of the Program's primary objectives of assessing whether agricultural chemicals are impacting groundwater. Since the vast majority of pesticides found during the Program's monitoring have been below any drinking water standard or health advisory level, and pesticides are not naturally occurring in groundwater, the selected criteria for the priority score was pesticide detections. Thus the priority score would be based on whether there is any pesticide present, even if the concentrations were quite low. Nitrate, on the other hand, is naturally occurring with some estimates of natural background concentrations being in the two to three mg/L range. Therefore, the priority score is based on the nitrate maximum contaminant level (MCL) of 10 mg/L, in order to account for naturally occurring nitrate in groundwater.

The intent of these criteria is to identify those areas that currently have observed nitrate and pesticide present in groundwater and monitor those areas for future changes. Conversely, areas without the presence of nitrate exceeding the drinking water standard or pesticide detections would receive a lower priority, as the water quality results indicate that agricultural chemicals are not a significant problem. Based on this philosophy, the following raw criteria scores are assigned based on existing groundwater quality results.

Table 3 – Criteria for Assigning the Raw Score for the Nitrate Exceedance Levels and Pesticide Detections.

Nitrate Exceedance Levels (percent samples with NO_3-N $\geq$ 10 mg/L)	**Pesticide Detections** (percent samples with a pesticide detection)	Raw Score
1 - 5	1 - 3	1
6 - 10	4 - 7	2
11 - 15	8 - 12	3
16 - 25	13 - 20	4
> 25	> 20	5

One key factor in assigning a score for nitrate exceedances and pesticide detections is the use of percentages to arrive at the final score. This procedure should help to minimize any bias that may be introduced due to differences in the amount of historical data available. Areas that have not been extensively sampled could potentially be at a disadvantage if percentages were not utilized, leading to a lower priority ranking and ultimately fewer additional sampling and monitoring events. For example, if raw numbers of exceedances were used, a reconnaissance level investigation utilizing ten wells with one well having a concentration greater than 10 mg/L it would score lower than a 130 well regional monitoring effort where 13 wells had similarly high concentrations. Yet, both of these investigations have the same overall percentage (10%) of wells exhibiting nitrate exceedances.

Other data factors, besides the issues with the amount of data, that need to be considered when assessing the raw score for the nitrate exceedances and pesticide detections, include using third-party data. These data, which typically represent data that have not been collected by the Program, also need to be assessed for quality assurance purposes. In the past, the Program has worked cooperatively with other agencies when monitoring a specific area. Important considerations when utilizing another agency's data include such things as detection levels (both lower and higher), and standardized sampling procedures. Incorporating third-party data with detection levels dramatically different than those achieved by the Program need to be carefully considered. Using data that had detection levels considerably lower than those typically employed by the Program may produce an unrealistically high percentage of pesticide detections. On the other hand, data obtained using higher than normal detection levels may inadvertently reduce the percentage of pesticide detections. As analytical laboratory methods are continually evolving and improving, the Program is continually assessing currently available detection levels. Data that falls outside these expected detection levels needs to be assessed on a case-by-case determination prior to being utilized to determine a raw score. Analogously, water quality results can be influenced by field and sampling procedures, therefore the Program will typically assess whether third-party results were collected utilizing accepted sampling protocols prior to using the data for determining a priority matrix.

Pesticide and Fertilizer Use

To derive the score for pesticide use, the Program has taken the total pesticide use data published by Matti (2001) (Figure 7, Section IV), and created a county-wide average pesticide use map using the area of each county. Each county was assigned a numeric score based on one of five estimated use categories that were determined using Jenk's optimization (i.e. a GIS based statistical method to find natural data groupings). Those counties with lower estimated use rates were assigned a raw score of one, and Alamosa County was assigned a score of five, as the only county in the high use rate category.

In some cases, this approach could still present issues with regard to accurately portraying the use of pesticides. For example, the original data was collected based on the location of the original purchase of a particular pesticide, and therefore cannot reflect possible transport to, and subsequent application in, other counties. Other issues include examples such as Larimer County, where the majority of the applications are known to occur predominately in the eastern portion of the county. To account for some of these differences, the weighting factors assigned for pesticide use are lower than those utilized for the other criteria.

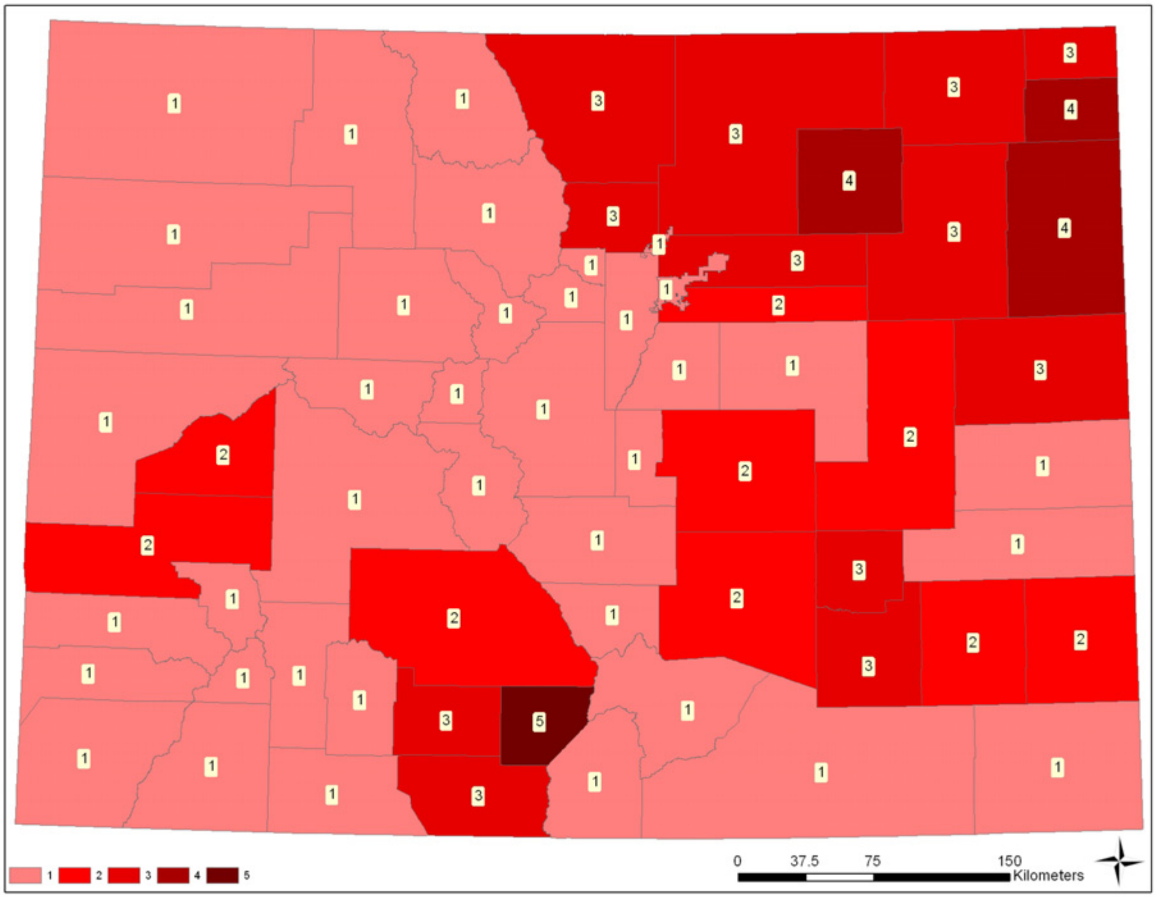

Figure 9. Raw Scores Based on Normalized Pesticide Use

To estimate fertilizer use, the Program utilized the nitrogen use data developed by Ruddy et. al. (2006). Each county was assigned a numeric score based on one of five use rates, as was done for the pesticide data. Counties with the lowest use rates were assigned a raw score of one, while counties with the greatest use rates were assigned the highest raw score of five. The city and county of Broomfield was incorporated after the available time frame from which pesticide and fertilizer data were available, so estimates for use rates in Broomfield were estimated from the surrounding counties.

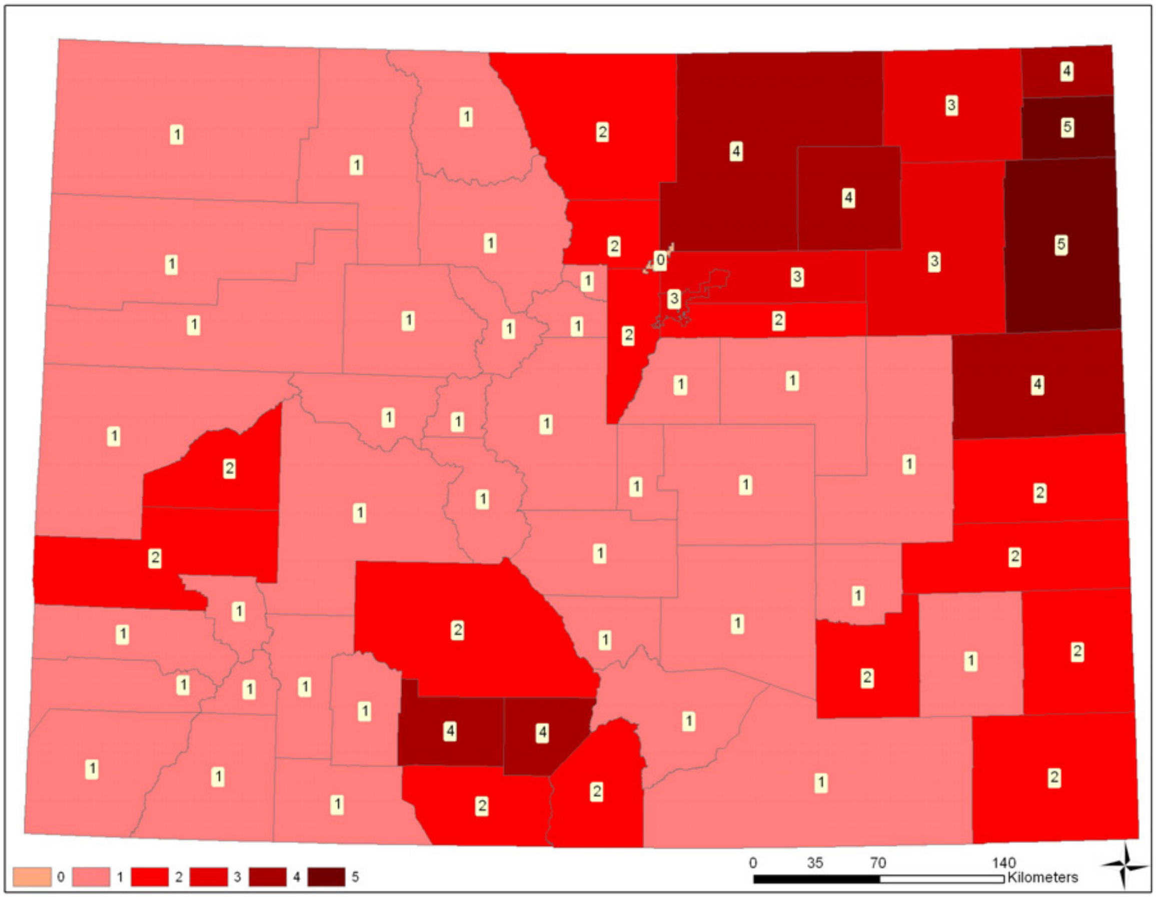

Figure 10. Raw Scores Based on Normalized Nitrogen Fertilizer Use

<u>Aquifer Sensitivity and Vulnerability</u>

Aquifer sensitivity and vulnerability is one of the key components of the priority matrix, and for both sampled and un-sampled regions, represents the most important criteria. However, all of the original sensitivity and vulnerability studies utilized a grid system that typically varied between one and two kilometers in size. While this resolution is key to understanding variations within an aquifer, it does not provide a single value for the entire aquifer that could be utilized in the priority determination.

To produce a representative single value on an aquifer scale, a weighted average of the sensitivity and vulnerability results was computed for the major aquifers in Colorado. Within an aquifer, each sensitivity, or vulnerability category, was multiplied by the corresponding area calculated using the original grid size. The sum of these results is then divided by the entire area of the aquifer. The resulting numeric value then represents the average sensitivity, or vulnerability, of the aquifer (Table 4).

Example Application of the Priority Matrix

The Weld County monitoring network in the upper South Platte River basin represents one of the Program's high monitoring priorities over the past ten years. This area is well known throughout the State as a key agricultural area, and Weld County was recently identified as one of the fastest growing counties in the United States. The Program has, and will continue to, consider this a high priority area for continued monitoring.

For Weld County and the upper South Platte River, the priority score would be determined by first assessing the available groundwater monitoring data for nitrate concentrations in excess of the MCL (10 mg/L) and the number of pesticide detections. The Program as amassed a considerable amount of data from this area, and based on both the percentage of pesticide detections and nitrate concentrations greater than 10 mg/L, would receive raw scores of five for both criteria (Table 3). Based on pesticide and fertilizer usage, the raw scores would be three and two, respectively (Figures 9 & 10). The aggregate nitrate vulnerability was 2.18, while the aggregate pesticide sensitivity was 1.42. Based on these raw scores, the final weighted (see Table 2 for weighting factors) score for upper South Platte River and Weld County was 36 (i.e. score times weighting factor = (5x2) + (5x2) + (3x1) + (2x1) + (2.18x3) + (1.42x3) = 35.8 ≈ 36).

North Park is an example of the application of the matrix for a relatively low priority area. In 2000, the Program sampled approximately 20 wells in the North Park area of Jackson County. The groundwater sampling results indicated that nitrate concentrations for all wells sampled were below 10 mg/L. Additionally, only one pesticide was detected at a single well, yielding a pesticide detection percentage of 1.7%. Therefore, based on these results, the nitrate exceedance and pesticide detection scores would be zero and one, respectively (Table 3). The pesticide use and fertilizer use scores would both be one (Figures 9 & 10). The aggregate nitrate vulnerability score is 1.64, and the corresponding pesticide sensitivity score is 1.33. The final weighted score (see Table 2 for weighting factors) for North Park would then be 13 (i.e. score times weighting factor = (0x2) + (1x2) + (1x1) + (1x1) + (1.64x3) + (1.33x3) = 12.91 ≈ 13).

Results of the Priority Matrix

The Program has applied this decision matrix to the major agricultural and urban areas of the State, and the resulting priority scores are presented in Table 4. The resulting weighted priority score is a function of factors specific to that region. Areas with high weighted priority scores represent areas where the potential for possible impacts from agricultural chemicals would be greater than areas with lower weighted priority scores. Consequently, the Program plans to focus monitoring efforts on those areas with higher weighted priority scores.

One alternative that was considered was scoring each area independently for nitrate and pesticide in order to assess whether a particular area should be considered a priority for one but not the other during future monitoring. This type of an approach would create a nitrate and pesticide specific priority score. For example, a particular area could exhibit high nitrate vulnerability, but also have a low corresponding pesticide use score, in which case it may potentially indicate an area where focusing on nitrate monitoring would be more appropriate. However, after calculating individual priority scores for nitrate and pesticide, the relative ranking for the various regions remained nearly the same. For nitrate specific priority scores, the only difference was that the Arkansas River alluvium scored higher than the Urban Front Range. Otherwise, the relative rankings of the various regions remained the same. For pesticide specific priority scores, a similar result was observed with the High Plains Aquifer region ranking above the Arkansas River alluvium, with the other relative rankings remaining the same. This result was not unexpected, as these three regions are the only regions that exhibit differences in the raw scores for nitrate exceedance and pesticide detections; the most heavily weighted components used for the final priority score.

Since the use of nitrate and pesticide specific priority scores had little impact on the overall ranking of the regions, a single weighted priority score, as shown in Table 4, was used to prioritize regions for sampling. There are several other reasons for not treating regions independently with respect to monitoring for nitrate and pesticides. A key factor to sampling efficiency is the ability to simultaneously collect water samples for both nitrate and pesticide analysis. By keeping the monitoring for nitrates and pesticides together, the logistical preparation for collecting samples is minimized. Additionally, C.R.S. 25-8-205.5, the Agricultural Chemicals and Groundwater Protection Act, defines agricultural chemicals as *all pesticides and commercial fertilizers used in both urban and rural settings*. Therefore, by including both fertilizers and pesticides in the weighted priority score, the Monitoring Program is more succinctly addressing the goal of the Act.

Table 4 – Decision Matrix for Obtaining a Monitoring Priority Score.

Region	Nitrate Exceedance Score	Pesticide Detection Score	Fertilizer Use Score	Pesticide Use Score	Nitrate Vulnerability Score	Pesticide Sensitivity Score	Weighted Priority Score
Lower So. Platte	5	5	3.6	3.4	2.50	1.71	40
Upper So. Platte/Weld County	5	5	3.0	2.0	2.18	1.42	36
San Luis Valley	4	4	2.8	2.8	1.97	1.56	32
Urban Front Range	3	5	1.6	1.8	1.74	1.06	28
Arkansas River	4	3	1.4	2.4	1.79	1.16	27
High Plains Aquifer	2	4	2.7	2.3	1.78	1.10	26
West Slope/Tri-rivers	1	1	1.7	1.7	2.84	2.69	24
North Park/Jackson Co.	0	1	1.0	1.0	1.64	1.33	13

V. Determination of Sampling Return Frequency and Proposed Long Term Schedule

The second critical aspect of identifying high priority areas involves how often that area is to be sampled. Since high priority areas represent those areas most vulnerable to potential contamination due to agricultural chemical use, these areas should be sampled on a more frequent basis. Conversely, those areas with a relatively low weighted priority score are areas where the potential for agricultural chemical-related groundwater contamination is low, and less frequent sampling would be necessary to monitor groundwater quality.

The question of how often to return to an area previously sampled should be based on an analysis of the data utilized to arrive at the weighted priority scores. These scores take into account all of the factors that the Program has currently identified as key components with regard to groundwater impacts. The median weighted priority score was approximately 28, and therefore this would appear to represent a logical starting point for estimating potential return frequencies.

As described in the previous section, the weighted priority score for North Park in Jackson County was 13, and represented an area where additional monitoring efforts were considered a low priority. Therefore, based on the distribution of the priority scores for the existing areas, low priority areas would be considered those with a score of less than 20. For these areas, the Program goal would be to re-sample approximately once every ten years, as an unspecified sub-regional monitoring effort. This is not to imply that if a special situation arises sampling could not occur on a more frequent basis, but rather barring dramatic changes in agricultural practices the goal would be to sample approximately once per decade.

Priority scores between 20 and 30 included four areas, the West Slope/Tri-rivers area, the High Plains Aquifer, the Urban Front Range, and the Arkansas River alluvium. These areas represent approximately one-half of those areas for which weighted priority scores were calculated. These areas would represent an intermediate priority, with a goal of sampling approximately once every five years.

Three areas, the San Luis Valley, the upper South Platte/Weld County, and the Lower South Platte, all had weighted priority scores greater than 30. For these areas, the goal of the Program would be to sample on an interval of approximately once every three years.

Monitoring networks that have been established represent those areas where the Program has identified either a special concern or a vulnerable area that warrants more frequent monitoring (i.e. upper So. Platte/Weld County, Arkansas River alluvium). The goal of the Program for these areas would be to attempt to sample annually. However, another limiting factor that must be taken into account, at least in the short-term, is the number of samples that the Program's laboratory can process. Currently, the Program's laboratory has the capability of analyzing approximately 150 samples annually. Steps are currently being taken to increase this limit, but full implementation is not expected until early 2008.

Based on the weighted priority scores, the following table (Table 5) summarizes the anticipated sampling frequency for those areas that the Program currently has assessed. In the future, as additional agricultural areas of the State are investigated, the table will be updated to reflect the current status of both existing and new areas.

Table 5 - Summarizing the Program Goals Regarding Sampling Frequency.

Weighted Priority Score	Proposed Sampling Frequency
Less Than 20	Once a decade as an unspecified sub-regional monitoring effort, unless dramatic changes in existing agricultural practices occurs.
Between 20 & 28	Sampled at between three and five-year intervals.
Greater Than 28	Sampled at approximately two-year intervals.
Monitoring Networks	Sampled annually, as conditions permit.

Based on this sampling frequency, the Program has established a long-term sampling plan that covers the next ten years (Table 6). The plan currently calls for a two-year period for laboratory upgrades that will increase sample analysis capacity to approximately 200 samples per year. Beginning at this same point in time, would be a scheduled expansion of the Monitoring Program to areas that currently lack any baseline data. There is also an additional two-year decrease in sampling in the years 2014 and 2015 to allow for an additional sub-regional monitoring or to account for any potential scheduling conflicts. As currently envisioned, the Program would ultimately have an annual capacity to process approximately 220 samples per year.

Table 6 – Projected Ten-Year Long-Term Sampling Plan for the Colorado Agricultural Chemicals and Groundwater Protection Program

	Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Geographic Region	**Weighted Priority Score**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**	**Est.# Samples**
Lower So. Platte	40		20		20		20		20		20	
Upper So. Platte / Weld County Monitoring Network	36	80	80	80	80	80	80	80	80	80	80	80
San Luis Valley	32	40		40		40		40		40		40
Urban Front Range	28	60			60			60			60	
Arkansas Valley Monitoring Network	27		20		20		20		20		20	
High Plains Aquifer	26		75					75				
West Slope/Tri-rivers	24			60					60			
Sub-Regional Monitoring (To Be Determined)	?		50	50	50	50	50	50	50	50	50	50
	Estimated Annual Total Number of Samples	180	245	230	230	170	170	305	230	170	230	170

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