# Sub-Surface Mapping & Aquifer Assessment

Last Updated Thursday, 19 March 2009

BASALT AQUIFER RECHARGE, AGE, AND WATER LEVEL IN THE COLUMBIA BASIN GROUND WATER MANAGMENT AREA An Introduction to the Columbia Basin GWMA Subsurface Geologic Mapping and Hydrogeologic Assessment ProjectINTRODUCTIONThe Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties (the GWMA) currently encompasses approximately 8,300 square miles in south-central Washington (Figure 1).  When first designated in February 1998, in response to concerns about elevated nitrate-N concentrations in groundwater, the GWMA included all of Franklin, Grant, and Adams Counties.  In 2005 Lincoln County was added to the GWMA, and the GWMA charter was expanded to include all groundwater quality issues in the four counties. The photos in this article when clicked on will open in a larger format.{gallery}subaquifer/figure1{/gallery}Scientific, mitigation, planning, and outreach activities dealing with groundwater quality within the GWMA largely are guided by the GWMA Plan.  Based on conclusions presented in the GWMA plan and Ecology review comments on the GWMA plan, GWMA stakeholders decided that there was a need to identify the aquifers contributing groundwater to GWMA sampling wells, the extent of those aquifers, and the recharge sources (if any) for these aquifers.  To support this, the GWMA Subsurface Geologic (or Hydrostratigraphic) Mapping Project was started in 2000. At this time, the subsurface geologic mapping effort has mapped the distribution of the major geologic features and units that influence ground water occurrence and movement beneath the GWMA.  GWMA’s subsurface geologic mapping efforts have been done in phases tied to changing GWMA priorities and funding availability.  These phases were as follws:

- During 2000, 2001, and 2002 the mapping project focused on the shallower parts of the basalt aquifer system in Adams, Franklin, and Grant Counties.  This work was done to better understand the occurrence of nitrate in the shallower portions of the basalt aquifer system.
- Between 2002 and 2004 the sediments overlying the basalt aquifer system in the 3 original GWMA counties were mapped.  The sediments were mapped to better assess the impacts of nitrate bearing shallow ground water on private, single family domestic exempt wells.
- Beginning in 2006 and continuing through the current effort which began earnest late in 2007, the mapping efforts have extended into Lincoln County (flowing the addition of Lincoln County to the GWMA) and downwards into deeper parts of the basalt aquifer system.  This emphasis on the deeper basalt aquifer system, especially within the Grande Ronde Basalt, has been driven by the growing concern for sustaining deep aquifer production wells for both agriculture and municipalities.  As a part of the recent subsurface mapping work, GWMA’s efforts have begun to evolve, focusing more and more on understanding ground water sources.  This change in emphasis is a direct consequence of the legislative mandate which funded the GWMA mapping efforts in 2007, 2008, and 2009.  Specifically, this work was funded by a direct appropriation from the Washington State Legislature, which was directed to the GWMA via the Washington Department of Ecology (Ecology). A key objective of this work, as mandated by the Washington State Legislature, was to:“…submit a report to the appropriate committees of the legislature describing the dynamic relationship between groundwater and surface water in the region.”To that end, GWMA hydrogeologists currently are working on a report that refines and upgrades the GWMA geologic database and geographic information coverage (GIS) by essentially completing the subsurface geologic mapping portions of GWMA’s subsurface mapping project and using this information in conjunction with water quality, water level, and well testing data (both existing and new) to test and refine the conceptual model describing ground water flow in the aquifers underlying the GWMA and the relationships of this groundwater to surface waters, including recharge. The basic project approach used to accomplish this goal is described in a work plan produced in mid 2007.  The remainder of this progress report focuses on key aspects of this larger effort, especially as it relates to the legislative request that accompanied the funding authorization.This progress report is subdivided into several sections which address the basic legislative request, including:
- A discussion of the potential recharge, or lack of recharge, of the Columbia River basalt aquifer system beneath the GWMA that comes from the Lake Roosevelt pool.  Our work suggests there is little or no recharge of the basalt aquifer system underlying GWMA from Lake Roosevelt.
- The potential for recharge of this aquifer system from areas lying east of the GWMA boundary.  This may be occurring, but the impact of this recharge on the regional aquifer system appears to be minimal.
- A review of groundwater geochemistry data collected by GWMA scientists to investigate the age and potential for modern recharge of the aquifer system.  The deep ground water system is dominated by waters 10,000 or more years old.
- An evaluation of water level data in wells within the GWMA.  This data was examined to assess the degree of connection between the different parts of the CRB aquifer system.  Ground water in the GWMA appears to occur in sub-basins displaying limited connections.
- A review of GWMA’s conceptual model of how ground water recharges CRBG aquifers, moves through those aquifers and potential discharges from those aquifer systems.It is not the intent of this report to describe all of the work and results of the current GWMA subsurface mapping and aquifer assessment effort.  That will be done later in the spring of 2009 in one or more technical reports currently being prepared by GWMA hydrogeologists.  CRBG Aquifer System and Lake RooseveltLake Roosevelt, the reservoir impounded by Grand Coulee Dam, lies on the northern edge of the Columbia Basin and the basalt aquifer system hosted by the Columbia River Basalt.  This aquifer system characteristically consists of a series of individual water-bearing zones, or aquifers, that are confined between the widespread layered basalts that comprise the Columbia River basalt.  Each of these layers, which are stacked one a top the other, typically range from 50 to 150 feet thick, and the tops and bottoms of them consist of rubbly to vesicular rock that can host groundwater.  The zones between each basalt flow layer are known as interflow zones and they consist of the bottom few feet of one basalt flow layer and the upper few feet of the underlying layer. Figure 2 shows the extent and

elevation of the top of the deeper aquifer system in GWMA, the Grande Ronde system.Groundwater within this layered basalt system moves down slope (down dip) away from recharge areas.  Recharge generally occurs where an interflow zone is close to the ground surface and in contact with surface water, such as a stream, river, lake, or reservoir, or in high precipitation areas.  Within the Columbia Basin, high precipitation areas usually are at higher elevations around the edge of the Basin or on high ridges within the basin (where precipitation is significantly higher than in the low land central basin).  Surface water, where present, usually is found in the deep coulees and in areas where basalt interflow zones are exposed in major river canyons. In and near the GWMA, the largest body of surface water is Lake Roosevelt.  Given that, the GWMA team looked at the physical relationship between Lake Roosevelt and the basalt aquifer system to evaluate the potential for recharge of GWMA basalt aquifers by the reservoir.  This was done using a combination of subsurface geologic maps produced through the subsurface geologic mapping effort and water level data previously collected by the Department of Ecology as part of their long term aquifer monitoring program in the Columbia Basin.  Based on this information, GWMA’s basic conclusion is that Lake Roosevelt is not a source of significant, if any, recharge to the Columbia River basalt aquifer system.  Aquifer hosting interflow zones in the basalt aquifer system, with only one exception within the GMWA, simply do not come into physical contact with Lake Roosevelt.  Everywhere along the length of the reservoir within GWMA, basalt almost everywhere is found several hundred feet above the reservoir pool.  In fact, the basalt lies atop granite and other older pre-basalt rocks (basement) that are very impermeable.  This basement rock physically separates the basalt aquifer system from the water found in Lake Roosevelt.  There is no way for water within the reservoir to go up hill across the basement rocks above the reservoir and into the basalt interflow zones found along the crest of the ridges above the Reservoir.  Figures 3 and 4 illustrate this physical relationship. {gallery}subaquifer/figure2{/gallery}This observation is confirmed by water level data in a a number of wells where Ecology has collected water level data over the past 20 to 30 years.  Water levels in these wells are several hundred feet higher than the pool elevation.  If the primary recharge mechanism for the basalt aquifer system being measured by these wells was the reservoir, water levels in them would be at or below the reservoir pool elevation.  This tells us that the primary influence for water level in these wells is related to recharge at elevations higher than the reservoir pool.  Figure 3 shows this relationship.  {gallery}subaquifer/figure3{/gallery}{gallery}subaquifer/figure4{/gallery}Figure 3 also shows the presence of a basement ridge buried beneath the basalt and separating the basalt aquifer system from the reservoir pool.  This ridge, which our mapping shows extends the full length of Lake Roosevelt on the northern edge of GWMA provides a further physical barrier to recharge of the basalt aquifer system by the reservoir.  The one exception to this is at Hawk Creek north of Davenport, Washington.  In this area the basalt system does come into physical contact with the reservoir, and local basalt water wells suggests local recharge of basalt by the reservoir.  However, GWMA’s subsurface basalt mapping again shows that the buried basement surface may be highe enough south of the reservoir to greatly restrict, if not completely block, the southward movement of reservoir recharge through the basalt and into the regional basalt aquifer system.Recharge from the East of GWMA The subsurface geologic mapping effort also traced the extent of buried basement highlands within GWMA southwards in the eastern portion of Lincoln County (Figure 5).  In this part of GWMA, as well as the eastern portion of the State, these buried basement highlands occasionally come to the surface, forming hills projecting above the basalt.  These hills, known as steptoes, are like their namesake Steptoe Butte, common in northeastern Lincoln County (in GWMA) as well as western Spokane County and central Whitman County. Where present, these buried hills probably form barriers to groundwater movement from the higher precipitation areas along the Idaho/Washington border into the greater GWMA region.   {gallery}subaquifer/figure5{/gallery}  This relationship holds true for the West Plains area of western Spokane County. Again, these basement highlands, buried beneath the basalt, form buried hills that interrupt the lateral continuity of basalt interflow zones, and the potential movement of ground water eastwards into the GWMA region.   Ground Water Geochemistry, Age, and Recharge Relationships The water sources that recharge the aquifer system, and the length of time it has taken for water from various sources to arrive at the location of a given well are recorded in the chemistry of groundwater.  In particular, different recharge sources (ancient glacial meltwater, irrigation waters, recharge from present-day surface waters such as lakes, rivers, and canals) can be identified using geochemical tracers and groundwater dating
methods. {gallery}subaquifer/figure6{/gallery}As part of this study to characterize the aquifer system, selected irrigation, municipal and private supply wells, as well as surface water bodies representing potential recharge sources, were sampled and analyzed for a suite of geochemical and isotopic parameters including major and trace element concentrations, stable isotopes, dissolved gases and age tracers (radiocarbon, tritium, atmospheric chlorofluorocarbons or CFCs) in order to elucidate the origins and hydrochemical evolution of the groundwater and, in particular, to evaluate recharge relationships and timescales in the deeper basalt aquifer system. Tritium and CFCs are used to identify and quantify recent recharge components (a few decades to a few years old), whereas radiocarbon is useful for identifying groundwater that is hundreds to tens of thousands of years old. By combining data for age tracers with different characteristic timescales, it is possible to estimate the time elapsed since the water entered the subsurface and also to identify mixtures of older and younger groundwater in production wells. This information was used in conjunction with the geologic model to identify connections to current potential sources of recharge in the aquifer system. As shown in Figure 6, relatively young groundwater recharge ages (less than 50 years) are generally found for shallow wells open to unconfined sediment aquifers, indicating direct connections to present day recharge sources (canals, seasonally water-filled coulees, creeks and lakes).  In samples from some deeper municipal supply wells in basalt which are open over large vertical intervals, age tracers indicate the produced groundwater is a mixture of old (thousands of years) and young water entering from different flow zones with different connections to present day recharge. This data is used in combination with static water level trends, to evaluate the sustainability of current water extraction rates on a local and regional scale.  Radiocarbon and stable isotope data, and the absence of detectable tritium and CFCs, indicate that groundwater produced from deep irrigation wells in the Odessa area completed in the lower Grande Ronde basalt layers

is more than 10,000 years old. This part of the aquifer system has not been recharged since the end of the last ice age when climate conditions were cooler and wetter than present. Some specific examples of these findings are given below. Royal City – Recharge to Wanapum Aquifers Keeps Up With Demand (Figure 7) In the Royal City area in western Grant County, between the Frenchman Hills and the Saddle Mountains, municipal supply wells completed in the shallow basalt system (Wanapum) have apparent radiocarbon ages up to 1300 years old and detectable tritium indicating that part of the groundwater is less than 50 years old. This is direct evidence of a mixture of older water probably originating as precipitation on the Frenchman Hills and as well recent recharge from leakage beneath the nearby Frenchman canal. Static levels in these wells are stable, indicating that the recharge from natural and anthropogenic (canal leakage) sources is sufficient to meet municipal water demands in this part of GWMA.

Moses Lake Well 18 – Wanapum Well Recharged by the East Low Canal (Figure 8) Moses Lake Well 18 is also completed in the Wanapum (Lower Roza and Frenchman Springs Formations) and has historically stable static water levels. The water from this well is less than 50 years old as indicated by radiocarbon, tritium and CFC data, which implies a direct connection to nearby East Low Canal through Roza/Upper Frenchman Springs flow zones. Moses Lake Well 17 – Upper Grande Ronde Well With Limited Recharge (Figure 9)Moses Lake Well 17 is a deep well sealed into the Upper Grande Ronde (Sentinel Bluffs). Static water levels in this well are declining. The apparent radiocarbon age for groundwater produced by this well is approximately 6000 years, but contains detectable tritium, indicating a mixture of old and young water. The proportion of recharge from young water component is estimated to be less than 20 % and is too little to offset withdrawals (i.e. 80 % of the water production is derived from storage, therefore water levels are declining). There are no geologic features indicating a direct connection to surface water, therefore the young recharge component likely represents limited vertical leakage through the many uncased wells present in the vicinity of the town of Moses Lake. Current production rates from this well therefore are not sustainable as there is no reliable source of recharge to this part of the aquifer.
{gallery}subaquifer/figure7{/gallery}{gallery}subaquifer/figure8{/gallery}{gallery}subaquifer/figure9{/gallery}Odessa Area Deep Irrigation Wells – No Recharge to Lower Grande Ronde (Figure 9)  Deep irrigation wells sealed into the Lower Grande Ronde aquifer system in the Odessa subarea approximately 20 miles east of Moses Lake have declining static water levels, apparent radiocarbon ages ranging from 10,000 to 20,000 years and generally no detectable tritium or CFCs. In one example illustrated in Figure 4, a recently drilled well completed in the Umtanum and Ortley units with an apparent radiocarbon age of 15,800 years shows no geologic connection to any surface water recharge sources. The groundwater produced from this well is essentially non-renewable.Historical Ground Water Level DataEcology has measured groundwater levels for up to 40 years in numerous wells distributed throughout the Columbia Plateau and the GWMA.  As part of this effort, Ecology and the U.S. Geological Survey (USGS) constructed a number of multi-level observation well clusters around the GWMA in the 1970s and early 1980s to evaluate the state of the groundwater resource and the response of the basalt aquifers to development away from the direct influence (“noise”) of a pumping well.  Figure 10 shows a schematic representation of one of the multi-level well clusters. Groundwater elevation measurements obtained during the same discrete time period can be used as an indicator of possible connection between groundwater and surface water and how well connected the basalt interflow zones are laterally and vertically.  Regular measurements taken over a number of years, particularly from non-pumping wells, provide a record of pumping and recharge to the interflow zones monitored by the well.  The water level measured in each well represents the water pressure in the interflow zone(s) open to the well.  Similarities and differences in the levels and the trends between each well of a multi-well cluster define the relationship with interflow zones monitored each wells in the cluster.  If good vertical connection exists between interflow zones, we would expect the water levels in different zones to be similar, and to react similarly over time.  Conversely, differences in levels and/or trends indicate vertical separation between the monitored zones.  {gallery}subaquifer/figure10{/gallery}Groundwater elevation measurements obtained during the same discrete time period can be used as an indicator of possible connection between groundwater and surface water and how well connected the basalt interflow zones are laterally and vertically.  Regular measurements taken over a number of years, particularly from non-pumping wells, provide a record of pumping and recharge to the interflow zones monitored by the well.  The water level measured in each well represents the water pressure in the interflow zone(s) open to the well.  Similarities and differences in the levels and the trends between each well of a multi-well cluster define the relationship with interflow zones monitored each wells in the cluster.  If good vertical connection exists between interflow zones, we would expect the water levels in different zones to be similar, and to react similarly over time.  Conversely, differences in levels and/or trends indicate vertical separation between the monitored zones.
 Observations from Multi-level Well Clusters Review of historical groundwater levels from multi-level well clusters demonstrate that there is little vertical flow between the basalt interflow zones, and the aquifers comprised of these zones are separate and distinct.  The water levels from multi-level well clusters located throughout the GWMA corroborate this observation.  Figures 11 and 12 show a vertical profile of historical water level trends in two different parts of the GWMA.{gallery}subaquifer/figure11{/gallery}Figure 11, which depicts water levels from a multi-well cluster west of Odessa, shows that each zone has a distinctly different water level.  While all three zones show declining water levels from the beginning of monitoring in 1973, each zone shows a different trend, and those differences are maintained over the entire record.  The shallowest zone (M02) experiences the most declines between 1973 and 1990, whereas the deepest zone (M04), exhibits a lesser water level decline over the same period, followed by a drastic increase in the rate of decline after 2000.  This increase in the rate of decline in the deeper zone reflects the shift in pumping from shallower to deeper aquifers in the Odessa area. The relatively high water level in the deepest zone illustrates a high degree of confinement and isolation from the shallower zones. While the drilling into the deep zone would restore the water level in a well that was originally completed in one of the shallower zones, the sharp rate of decline also shows that the deepest

zone is isolated from the others, and that the higher water level condition realized by drilling into deeper zones is temporary. {gallery}subaquifer/figure12{/gallery}The water levels in the multi-level well cluster shown in Figure 12 also show that each zone is vertically distinct and separate.  The water levels in wells completed in Wanapum interflow zones are significantly higher than the well completed in the Grande Ronde and show recovery from pumping in the 1970s. Water levels in the Grande Ronde show relatively heavy pumping pressures and decline throughout the period of record. Water level elevations and historical trends in multi-level well clusters in the GWMA were evaluated with respect to the geologic framework of the Columbia River Basalt.  The water level data clearly show that basalt interflow zones form separate and distinct aquifers, In addition, the data corroborate anecdotal evidence that groundwater levels in the monitored aquifers hosted by the Grande Ronde Basalt are declining.  Declines in the aquifers in the Grande Ronde in areas where deep well irrigation is prominent commonly exceed 100 to 150 feet.  These observations have several implications:  First, the data show that natural recharge to the aquifers in the Grande Ronde Basalt is minimal, and at a slow rate where it occurs.  Recharge to the aquifers in the Grande Ronde Basalt is minimal because of the lack of vertical connection between shallow and deep aquifer zones, and a sparcity of both possible recharge locations and recharge water.  The potential for recharge decreases with depth in the Grande Ronde.  Specific reasons that recharge to the aquifer zones in the Grande Ronde Basalt is minimal include:

- There are few places where interflow zones that can receive recharge are exposed to surface water or precipitation, and the amount of exposure diminishes to zero with depth in the Grande Ronde Basalt.  In other words, the deeper aquifers in the Grande Ronde are not connected to surface waters anywhere in the GWMA.
- The interflow zones that are exposed are relatively thin and do not provide much area for precipitation or surface water to infiltrate,
- Leakage from shallower basalt interflow zones to deeper zones is very small.
- Precipitation and winter/spring runoff is small in magnitude compared to pumping.

A second implication of the ground water level record in GWMA wells is that existing groundwater supplies in the deeper basalt units are not reliable or sustainable in the long-term, and thus continuing to drill deeper into progressively lower aquifers in the Grande Ronde Basalt is only a temporary solution for declining water levels and pumping rates.

Geologic Controls on Columbia River Basalt Aquifer System in the GWMAThe thick sequence of layered flood-basalt flows of the Columbia River basalt are prime sources of potable groundwater throughout their extent in Washington, Oregon, and Idaho.  Having a realistic and accurate understanding of how ground water enters and moves through these flood-basalt flows is of fundamental importance to anyone working with Columbia River basalt aquifer systems (e.g. resource assessments, contaminant transport/fate, aquifer storage/recovery, regulatory assessment).One of the most extraordinary features of the Columbia River basalt is the physical dimensions of individual basalt flow layers.  A conceptual understanding of the nature of Columbia River basalt flows plays a critical role in accurately interpreting some of the unique hydrogeologic aspects of the basalt.  During the peak period of basalt eruptive activity (Grande Ronde and Wanapum Basalts) it was common for eruptive events to rapidly (~2 to ~12 weeks) emplace individual flows having volumes of 500 to >1,000 mi3 and for the lava to cover areas >10,000 mi2 creating the largest known lava flows on the Earth.  This combination of huge volume and rapid emplacement typically produced simple sheet flows 50 to >300 feet thick.Columbia River basalt flows are typically very widespread, covering an average area of 10,000 mi2.  This, coupled with the physical geologic characteristics of CRBG flows indicates they formed as lateral extensive, uninterrupted sheets. This differs markedly from more typical compound basalt flows which display numerous, interfingering, discontinuous, lenticular layers.  The net hydrologic result of this is that the aquifers within the sheet flows typical of the CRBG occur as a series of layered, tabular, confined features (Figure 13).{gallery}subaquifer/figure13{/gallery}Aquifer horizons within the Columbia River basalt generally are associated with intraflow structures at the top (e.g., vesicular flow-top, flow-top breccias) and bottom (e.g., flow-foot breccias, pillow lava/hyaloclastite complexes) of sheet flows (Figure 13).  The interiors of thick sheet flows (in their undisturbed state) are for all practical purposes essentially impermeable and act as aquitards, typically creating a series of “stacked” confined aquifers within the Columbia River basalt aquifer system.

The dominant groundwater flow pathway within this aquifer system is horizontal to sub-horizontal along individual, laterally extensive, interflow zones.  Given the physical properties of the Columbia River basalt, outcrop observations, and interpretations of well hydraulics vertical groundwater movement through undisturbed basalt flow interiors is small to essentially non-existent.  However, vertical groundwater movement between layered CRBG aquifers is possible, but occurs predominantly under specific geologic conditions where basalt flow interiors are disturbed or truncated.

Figures 14, 15, 16, 17, and 18 illustrate the main geologic features that influence the lateral continuity of Columbia River basalt layers and the characteristics of the aquifers within them.

{gallery}subaquifer/figure14{/gallery}{gallery}subaquifer/figure15{/gallery}{gallery}subaquifer/figure16{/gallery}{gallery}subaquifer/figure17{/gallery}The current Columbia Basin GWMA subsurface geologic mapping and aquifer assessment project has mapped the distribution of the major geologic units comprising the CRBG aquifer system, and the features within it that potentially effect the lateral distribution of individual aquifers.  In addition, this work, which includes an evaluation of water level trends and ground water geochemistry provides GWMA scientists with important clues into the nature of: (1) aquifer continuity and extent, (2) aquifer interconnection, or the lack of that interconnection, (3) ground water recharge and the potential age of ground water within the CRBG aquifer system, and (4) ground water discharge, or the lack ot that, especially from deeper portions of the system.  The results of this project also give GWMA stakeholders insights into how to better manage the aquifer system, including ways to evaluate recharge project feasibility.{gallery}subaquifer/figure18{/gallery}CONCLUSIONS - CONCEPTUAL GROUND WATER MODEL FOR THE GWMABased on the results of GWMA’s subsurface geologic mapping and aquifer assessment project, the following basic conclusions with respect to natural aquifer recharge and the source of basalt aquifer ground water in much of the GWMA are drawn.

- There is little or no recharge of the basalt aquifer system underlying GWMA from Lake Roosevelt.
- There is a potential for recharge of the basalt aquifer system from areas lying east of the GWMA boundary.  However, the impact of this recharge on the regional aquifer system appears to be minimal.
- The deep ground water system is dominated by waters 10,000 or more years old, suggesting that the deep aquifer system was recharged during the Ice Age floods.
- Ground water in the GWMA appears to occur in sub-basins displaying limited connections.These observations are consistent with the geologic controls on ground water movement that we have interpreted from the subsurface geologic mapping, ground water geochemical analysis, and water level data evaluation done for this project. Based on these observation and interpretations, the ground water recharge and flow system in the Columbia River basalt aquifers underlying the GWMA is characterized by a series of separate, water-bearing layers found in interflow zones at the tops and bottoms of individual basalt flow layers.  These interflow zone layers, or aquifers, are separated by the dense, solid, unfractured basalt rock that forms the bulk of the basalt geology of the Columbia Basin.  The places where these interflow zone aquifers can receive recharge are where they are at and near the surface in direct hydrologic connection with surface water and high precipitation areas.  Once water enters these zones it moves more-or-less horizontally along individual basalt flow layers.  Vertical movement of ground water through dense, uninterrupted basalt flow layers is small. The understanding of the Columbia River basalt aquifer system within the GWMA that has resulted from this work has given GWMA stakeholders a clear picture of how this aquifer system works, where it receives natural recharge, and how artificial recharge activities can be used better manage Columbia River basalt aquifer ground water resources.