# Geo-Spatial Infrastructure in the Ukraine and Other Post-Soviet States.

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***ABSTRACT***

*The history, current status and future prospects for development of vector and raster format geo-spatial data in the Ukraine and several other states of the Commonwealth of Independent States (CIS) will be presented. Emphasis will be on specific applications of ESRI software and ArcGIS compatible data sets currently in use in a variety of applications in the CIS (the Republics of the Former Soviet Union) including in the Ukraine, the Russian Federation and the Baltic Republics. Problems and limitations in available data as well as examples of successful applications in the environmental, water resources, public health, cadastral, tourism, and civil engineering and telecommunications spheres will be discussed. In particular, the significant challenges facing GIS professionals in the states of the former Soviet Union will be recounted and the great potential for expanded use of the technology will be assessed.*

## PAPER BODY

## INTRODUCTION

Use of Geographic Information Systems (GIS) in the states of the former Soviet Union, a region sometimes referred to as the Commonwealth of Independent States (CIS) and comprising firstly the Russian Republic (largest in nation size in the world at over 17 million square kilometers with a declining population of approximately 141 million), the Ukraine with 46 million inhabitants squeezed into 603,000 square kilometers. Ukraine despite is higher population density is the largest country entirely within Europe. There are also the relatively wealthy but smaller Baltic States (Latvia at 64,000 square kilometers with 2.3 million people, Lithuania at 65,000 square kilometers with 3.6 million people and Estonia at 45,000 square kilometers with only 1.4 million people). The other European states of the CIS (Moldova at 33,000 square kilometers with 4.4 million people and Belarus at 207,000 square kilometers with 10 million people). The Caucasian Republics of the CIS are distinctly different from each other; they are Georgia at 69,000 square kilometers and 4.9 million people, Azerbaijan at 86,000 square kilometers and 7.7 million people and Armenia at 29,000 square kilometers with 3.3 million people.

The Central Asian Republics of the CIS include, most notably, resource rich Kazakhstan (area 2.7 million square kilometers and population 15 million), Turkmenistan (area 448,000 square kilometers, but inhabited by only 5 million people) and Uzbekistan (area 448,000 square kilometers and population 27 million) and the poorer and more isolated scenic mountainous Republics of Kyrgyzstan (area 198,000 square kilometers and population 5.2 million) and Tajikistan (area 143,000 square kilometers and population 7 million) (World Fact Book, 2007). This paper will only consider those Republics of the CIS states where examples of GIS use have been identified by the authors, which therefore does not include discussion of Moldova, Kyrgyzstan, and Tajikistan. This is not to say that GIS is not in use in these countries, but applications outside of perhaps in the oil and gas industry appear to be rather limited in these generally smaller and poorer Republics. This paper will focus on use of GIS in the Ukraine, but by way of comparison, examples of GIS use in Russia, and the Baltic, other European, Caucasian and Central Asian republics will be discussed as well, but in less detail.

## HISTORY

Russia prior to the time of Peter the Great cannot be considered a leader in cartography, in fact prior to the 17th century only two maps were published in the Russian language and virtually all maps of the country were in German and made by German cartographers, some of whom were residents of Moscow (Bagrow, 1975). However, under the Czarist government of Russia, beginning in the 18th century, high quality topographic and thematic maps were made largely for military and scientific purposes, but the vast character of the Russian empire impeded accurate topographic mapping (UNESCO, 2005). The lack of a system of cadastral mapping partially reflects the semi-feudal character of land ownership and land tenure in Czarist "Great Russia", White Russia and the Ukraine. Only in 1860 did the Russian Empire begin to do cadastral mapping and that was very crude and was designed to help former serfs and kulaks purchase land through something called a *zidzeme* (a land valuation map) which was both corrupt (it tended to overvalue land to make it difficult for peasants to purchase) but also incomplete, thus in Latvia only about a third of the land was actually mapped by the *zidzeme* prior to 1917 (Goba, 2006). In contrast, cadastral mapping and land partitioning was well developed in most parts of western Europe by the 18th century (and in the U.S.A. in the original 13 colonies and in other non-frontier regions progressively after 1791) and this cadastral mapping provides the foundation for much later comprehensive mapping in countries like Holland, Sweden, England and Germany. Also, Western European countries were generally much smaller and more densely populated than the Russian empire.

After the Russian revolutions of 1917, efforts to create topographic maps, as well as specialized maps for economic and hydrologic purposes were made by the central Soviet government working through the Academy of Sciences and the military but dissemination of these maps were hampered by several factors. The chaos of the civil war period and political repression in the 1930's all had a negative impact. For example in 1934 at the time when Stalinist political repression associated with the Kirov assassination was starting, the job of maintaining (and importantly of controlling access to) topographic maps was assigned to the NKVD (the Soviet secret police). Admittedly, nationwide mapping was not a primary function of the secret police, but unlike countries where maps were made by civilian agencies such as the U.S. Geologic Survey or Ordinance Survey of Great Britain, or even places such as Italy or Chile where topographic mapping was the responsibility of the military, in the Soviet Union it was a responsibility of the secret police for several decades. The disastrous impact of the German invasion and the impact of the cold war on the Soviet State also had drastic effects on development of accessible and accurate cartographic products and in general on adoption of new technologies. The resulting secrecy with which maps and other cartographic information was treated, and to a lesser extent is still treated, has had a effect of retarding adoption of geospatial technologies and limiting dissemination of topographic and other cartographic products. Likewise, the lack of private ownership of land under the socialist system made cadastral mapping largely irrelevant, thus the development of this important component of most modern multi-purpose geospatial data sets was less developed in the Soviet Union and hence in the CIS than in many other nations.

What was present in the Soviet Union was a skilled cadre of cartographers and geographers who were trained at a number of prestigious universities and were members of the Academy of Sciences of the Union of Soviet Socialist Republics (USSR) and the All-Union Geographical Society. These cartographers developed great skill in manual cartographic methods and to a lesser extent in aerial photography assisted mapping and in preparing and printing many large format thematic maps of soils, geology, hydrographic and urban planning issues (French, 1961). Unfortunately, large format multi-color paper maps and the techniques that created them have not proven easy to transition into a digital vector format and even less so into true GIS with accurate associated attribute data. Topographic maps which include street centerlines, contours, hydrography and some political boundaries and limited set of cultural features at a scale of 1:25,000 and 1:10,000 for urban areas for most areas of the former Soviet Union were developed and are currently available in a scanned color raster format. Also town plans were produced for many cities at a scale of 1:2,000 including those in the Soviet Union and many other areas of military interest to cold war era planners. Much of the available vector GIS data has been derived from digitizing these Soviet era paper aerial photography derived topographic maps.

Another important contribution of the Soviet Union to geospatial technology was the development of artificial satellites starting with Sputnik in 1957. Sputnik (Star in Russian) was the very first artificial satellite. Soviet and later Russian world leading prowess in space technologies came to dominate the approach to use of computers in mapping. Thus satellite imagery became very important to mapping throughout the CIS. When GIS began to evolve in the Soviet Union toward the middle and later years of the 1980's, it was essentially a raster-based image processing and mapping system approach. Of course, Raster GIS also developed in the USA (ERDAS), Australia (ERMapper) and other places. What does not seem to have developed very much in the Soviet Union was vector- based GIS and linkages to extensive attribute databases. Thus early examples of GIS from the Soviet Union, such as mapping of radioactive fallout from the Chernobyl disaster conducted in 1986-1987 time frame by the Kurchatov Institute in Moscow used proprietary raster based GIS. In the late 1980's several GIS programs were developed in Russia including MAG system developed by the Geography faculty of Lomonosov State University in Moscow and Geodraw and Geographist developed by the Centre for Geo-Information Research of the Geographical Institute of the Russian Academy of Sciences (Kaminski and Kotelnikova (2006).

Another legacy of Soviet geospatial activities was the establishment of coordinate systems, datums and geodetic networks of control points throughout the Soviet Union. These fundamental building blocks of accurate geodesy are still in use in the Ukraine, Russia and most other CIS States. In the Ukraine, for example the common coordinate system used in mapping is the CK-42 system which dates interestingly from 1942, a seemingly busy year for the Soviet Union to adopt a new coordinate system since it was the same year as many desperate battles such as the one at Stalingrad. Also in current use in the Ukraine is a Soviet era 1977 Baltic elevation datum. There are over 22,000 geodetic control points established in the Ukraine in the Soviet period, but 1%-2% are lost to urbanization and agricultural development and none have been reestablished in the Ukraine. Also the accuracy of these points, which were not determined using satellite geodesy, is problematic.

Up through the middle 1980s; the Soviet Union made strenuous, though ultimately unavailing, efforts to match the U.S. and NATO countries in terms of military technologies, including geospatial ones, many of which have dual uses. These include spy satellite programs such as SPIN which has more recently been commercialized and the partially successful GLONAS (Global Navigation Sputnik), which is a global positioning system and rival to the U.S. Defense Department's NAVSTAR GPS system. Efforts in topographic mapping on a nearly global basis were also very substantial. Thus Soviet topographic mapping efforts produced rather good 1:25,000 scale maps of the Soviet Union (much of the European portion at a scale of 1:10,000) and Western Europe and the USA at 1:50,000 (Canadian Cartographic Association, 2005). These maps, though at a smaller scale, were generally more up to date that the corresponding maps available for the U.S. from the USGS. Tobin, a provider of geospatial data and aerial photography to the U.S. oil and gas industry thought enough of the quality of these maps of the USA (which had been interpreted from then almost current Soviet remotely sensed imagery) to convert some to a digital format and from Cyrillic to English language labels for sale in the U.S. market.

The decades from 1980 to 2000, and particularly the ten year period from 1985 to 1995, were a period of rapid change and evolution for GIS, witnessing the movement of GIS from mainframe computer to laptop and from 9 mm tape to flash memory and from cumbersome stand-alone command-line based programs to customized desktop mapping applications. Unfortunately, this same period of time was one of economic and political decay, collapse, and chaos throughout much of the former Soviet Union. Successful development and implementation of GIS, particularly development of a comprehensive national geospatial infrastructure depends on many factors. These include capable national institutions, a strong and responsive educational system and adequate funding for new initiatives and technologies. These foundations for geospatial infrastructure development were largely absent in the last years of the Soviet Union and early post-Soviet period. The Soviet Union was fairly monolithic when it came to policies regarding mapping, but the level of development and strength of academic institutions did vary appreciatively between Republics and regions. Thus places like Moscow, Kyiv (Kiev), Saint Petersburg (Leningrad), Tallinn, Riga and Vilnius had higher levels of development and more generally the Baltic States, the Ukraine and the Western European portion of Russia and Belarus were more advanced. After the collapse of the Soviet Union in 1991 (coincidentally the same year ARCVIEW was released by ESRI) the Republics began to diverge in terms of their mapping and GIS activities.

Dr. Arif Mehdiyev (Mehdiyev, 2001) in an article entitled "On Our Own – Rebuilding Azerbaijan's Space Imaging Industry" describes the struggle of Azerbaijan, an oil rich Caucasian Republic, to chart its own course with respect to geospatial technologies in the chaotic period after the collapse of the Soviet system. In Azerbaijan, as in the Soviet Union, much of the emphasis was on raster based satellite image processing technologies rather than vector GIS. A big part of the formative problems of GIS and space imaging in Azerbaijan and presumably in other Post-Soviet States was determining what entities had ownership of what intellectual and physical property. Which entities had ownership rights to the buildings, computers, data and programs that had not only been state property but had often been highly classified assets of military rocket forces, etc. Also many projects under the Soviet Union had depended on input from specialized institutes and academies and ministries that were after 1991 headquartered in other countries, with problematic ties to each other. So, for example in Azerbaijan, GIS was under the authority of the Ministry of General Machinery Building of the Soviet Union prior to 1991. What GIS has to do with building machinery is an open question, but then again in some places in the USA, GIS coordination at the State government level has been assigned to water development agencies, or economic development agencies whose primary mission is also somewhat removed from GIS per se. Furthermore, in this transition period there was economic chaos and great difficulty with hyper inflation.

In certain other States of the CIS, the collapse of the central government provided opportunities, thus in the more western oriented and generally wealthier Baltic states efforts to start using GIS for such projects as cadastral mapping were undertaken almost immediately. These states have continued to be leaders among GIS developers and users in the former Soviet Union. Perhaps this is partly explained by their independence in the period from 1917 to 1940 or influence from surrounding GIS powerhouses such as Finland and Sweden. Thus in Latvia starting in 1992, the collapse of the Soviet Union brought a resurgence of activities that had been interrupted in 1940. This included attempts to develop independent telephone systems and property maps partially to facilitate land reform and redistribution of land and privatization. These developments fostered efforts at use of GIS for telecommunications and cadastral mapping that has place the Baltic States ahead of other regions of the CIS in these applications.

## CURRENT STATUS OF GIS IN UKRAINE.

In the Ukraine a national geospatial infrastructure development effort was adopted in 1996 and continued through 2002 various GIS layers were interpreted from existing 1:200,000 scale topographic maps for the entire nation and 1:10,000 scale maps for m major urban areas there is also selective digital aerial photography. These data sets have been used to develop a number of layers of vector GIS data. This work has been coordinated by the Scientific Research Institute of Cartography and Cadastre of the Ukraine in Kyiv (Karpinski & Lyashchenko, 2006). Larger scale mapping efforts have been undertaken by a variety of organizations such Kievvodokanal (the Kyiv regional water supply and water treatment utility) and by organizations such as the Ukrainian Land and Resource Management Center in Kyiv and by Ukrainian Scientific Research Institute of Ecological Problems in Kharkov (Karkiv) (Prydatko, 2002). This data includes a vector-based hydrographic network, an extensive network of irrigation canals and related features. Also such layers as land cover derived from classified remotely sensed imagery using ERDAS imagine and ARCVIEW and ArcGIS software has been developed for many of the forested regions of the Ukraine such as the Carpathians and also for the Crimea. There is also a road network represented by street centerlines, a set of point data for over 30,000 inhabited places and a nationwide set of boundary data including national and provincial (*oblast*), regional (*rayon*) and municipal (*gorsoviet*) and rural town (*polselki*) boundaries and boundaries of numerous features such as national parks and forest reserves.

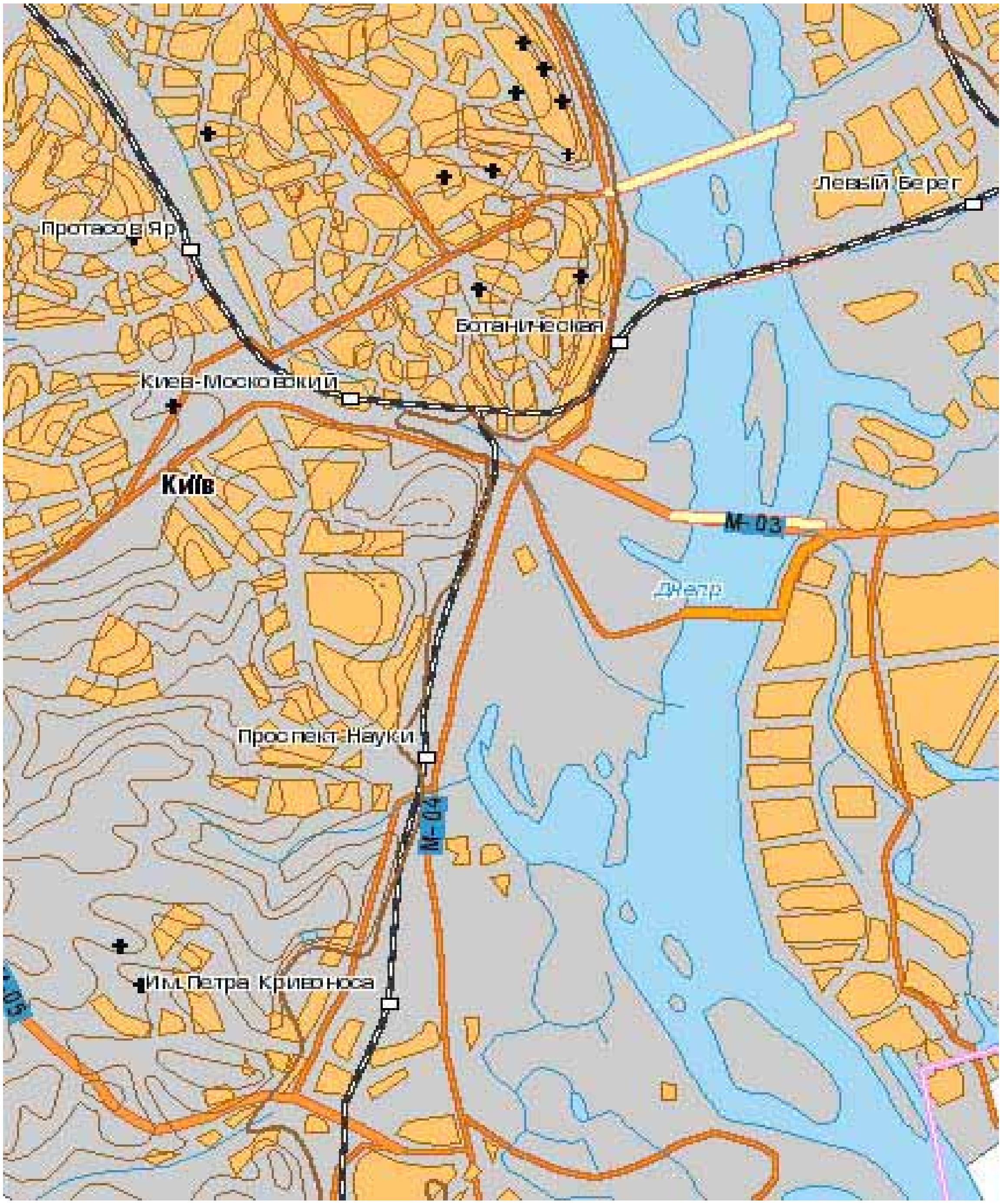



Figure 1. 1:200,000 scale vector data for the Kyiv region, is representative of GIS data available for the entire territory of Ukraine.

Figure 2. 1:10,000 scale vector data for the Obolon district of Kyiv is typical of the GIS data available for major urban areas of the Ukraine.

Figure 3: 1:2,000 scale vector data for the Obolon district of Kyiv contains building footprints and is used for municipal mapping and by utilities like Kyivvodokanal. This data is not generally publicly available.

In order to better disseminate this geospatial data among the various users in the Ukraine, a GIS web server has been established which consists of 4 actual servers running ArcIMS software. The Servers are centered on one in Kyiv, but other serves are in Lviv in Western Ukraine, Poltava in Central Ukraine and a fourth at Chernighiv in Northern Ukraine. There are also 34 clients on this secure network, most of which are universities or research institutes or regional governments. The web address of this system is VNETGIS.com. The money to start up this system, as well as the software used was provided by ESRI as part of a Global Geospatial Infrastructure Development grant in 2005 to the Scientific Research Institute of Geodesy and Cartography in Kyiv. See Figure 1 for a schematic of the Ukraine GIS web server layout.


Рис. 1.6. Топологія дослідної Української картографічної мережі

Figure 4. Schematic map of Ukraine GIS web server network.

Unfortunately, this Ukrainian national geospatial data has a rather limited set of attribute data associated with it. The attribute data structure is consistent for the materials produced from the topographic maps and is available in Ukrainian, Russian and English formats. However, newer data sets produced by other GIS users in the Ukraine do not have a consistent attribute schema and naming convention, hence street names and city names might differ regionally, particularly as adoption of Ukrainian as the official and only national language is being resisted in the Eastern Ukraine as well as in the Crimea. Also, some really important attributes do not seem to have been developed internally. Thus, for example the oblast and municipal boundary data lacks population demographic information. This limitation was recognized by a consortium of nine universities organized by Griffith University in Australia as the Australian Centre of the Asian Spatial Information and Analysis Network (ACASIAN) and the University of Melbourne's Center for Russian and Euro-Asian Studies. This group developed a Russian Federation and Former Soviet Republics GIS project starting in 1994. This project using ESRI software took attribute data from the 1989 Soviet Census of Population for the 120 *oblasts* (Provinces), 3,193 *rayon* (regions), 2,190 *gorsoviets* and 4,026 *poselki* and added it to vector format boundary files. The project also produced English language translations of this valuable geo-demographic information (ACASIAN, 2007). This project includes the Russian Federation as well as the Ukraine and other parts of the former Soviet Union. Some helpful GIS layers such as elevation data, and rail lines and airports do not appear to be part of easily available Ukrainian GIS data sets however. The lack of a set of vector rail line data is particularly problematic as rail travel is a very important mode of transport for long distance journeys in the Ukraine; scanned maps of the major rail lines are available from the Ukrainian Rail Ministry, however.

In addition to development of nationwide Ukrainian GIS data, various organizations have implemented GIS for more specific tasks and built geospatial data sets to support these tasks. Examples of such projects include work by the Emergency Situations Ministry which has used ESRI GIS software to map flooding in the Carpathians in the city of Chop with help from the U.S. Geological Survey and U.S. Agency for International Development (Schaub & Hern 2005). Another application of GIS in emergency response was undertaken in the city of Kharkov (Karkiv), the second largest in the Ukraine and center of aircraft production and higher education since the 19th century. There the Emergency Rescue Service used ESRI GIS software to improve provision of emergency services. In Kharkov, studies of how to respond to flooding and epidemic diseases have been made and ARCVIEW and ARCVIEW network analyst have been employed to map and study scenarios for mass evacuations and disaster response (Belogurov & Kosolapov, 1998). Also in the Carpathians, the Czech Republic based Institute of Forest Ecosystem Research has used ESRI GIS products with support from the Swiss–Ukrainian Forest Development Project to conduct statistical forest inventory in order to improve silvicutural practices and identify illegal logging activities that have been contributing to water quality issues and damage to habitat. (Vopenka & Cerny, 2006). The major black sea port of Odessa has used GIS to map and analyze port operations (perhaps inspired by the 500 layer GIS developed by the port of Rotterdam). UA Geomatics, Inc has worked to use GIS to map natural gas transmission lines and facilities for such major clients as GAZPROM, but perhaps most of this work has been using Ukrainian expertise to work on projects physically located in other Republics of the former Soviet Union that have greater natural gas and oil exploration and production related activities (UA Geomatics, 2002). These are all relatively small scale applications of the technology.

A different application of GIS in the Ukraine is demonstrated by the work of Geo-ecologists such as those at the Taurida National University in Sempheropol, the capital of the Autonomous Republic of the Crimea. The Crimea is a peninsula connected to the mainland of the Ukraine by narrow neck which has several highway and rail links running through it. In the heart of the Crimea are limestone mountains and along the Black Sea coast are many famous tourist attractions and natural areas. The Crimea has often been described as the "Russian Riviera" and has the mildest climate in the entire former Soviet Union due to the strong moderating influence of the surrounding Black Sea. The unique climatic setting has created many tourism related activities and ecosystem preservation projects of which Taurida National University is actively involved. Recently a project to map tourism related facilities using ArcGIS for potential interactive on-line mapping. Absence of hotel, and certain transportation data sets such as bus stations and routes makes development of tourism related interactive web-based mapping difficult.

A special set of GIS data was generated as a result of the consequences of what is arguably the worst industrial catastrophe in human history, the April 26, 1986 accident at the nuclear power generating station at Chernobyl in the northern Ukraine (Durbak, 2005). This includes work involves a great deal of raster format image processing as well as some vector GIS data creation and applied environmental modeling. One early example was SPOT (Systeme Probitoire et Observation de la Terre) imagery of the Chernobyl reactor taken on May 1, 1986 which showed the extreme heat generated by the reactor melt-down at a time the accident was being officially denied (NOVA, 2002). However, even earlier on April 29, 1986, a KH-11 (KeyHole 11 series spy satellite operated by the U.S. Defense Department) took images of the area with 6 inch resolution.

Work in Russia at the Kurchatov Institute using raster based GIS and ground based measurements of radioactive fallout produced maps of the downwind spread of the fallout over portions of the Ukraine, Belarus, and Poland and across the Baltic into Scandinavian. (Gilman, 2006). A change in wind direction after the first few days also meant that fallout affected the heartland of the Ukraine, including the Kyiv region. Besides the immediate effects of radioactive fallout on human health and the environment, there have been longer term effects which include population dislocations from a 30 kilometer diameter exclusion zone, an observed increase in cancer and other health problems and the costs of encasing the damaged reactor in a concrete sarcophagus and ultimately shuttering the largest power generation complex in the Ukraine (Gregorovich, 1996). Work by researchers at the University of Utrecht in the Netherlands to use GIS to model the environmental fate of Chernobyl derived radio-cesium involved use of a series of fate and transport models to predict contamination of the human food supply with radioactive cesium, which is treated by the human body as calcium and is thus a series health threat. This work demonstrated both the scope of the disaster, its long term ramifications and the utility of GIS in modeling the issues involved (Perk, et al, 2000). GIS has also been used as part of assessment of the impact of Chernobyl conducted by the Nuclear Safety Institute of the Russian Academy of Sciences (Bolshov, et al 1998). Other work on the impact of Chernobyl is described below in the section on GIS use in Other European Republics of the former Soviet Union, since Belarus in particular was impacted by this unprecedented accident.

## CASE STUDY OF USE OF GIS AT KYIVVODOKANAL FOR IN WATER RESOURCES PLANNING AND MANAGEMENT

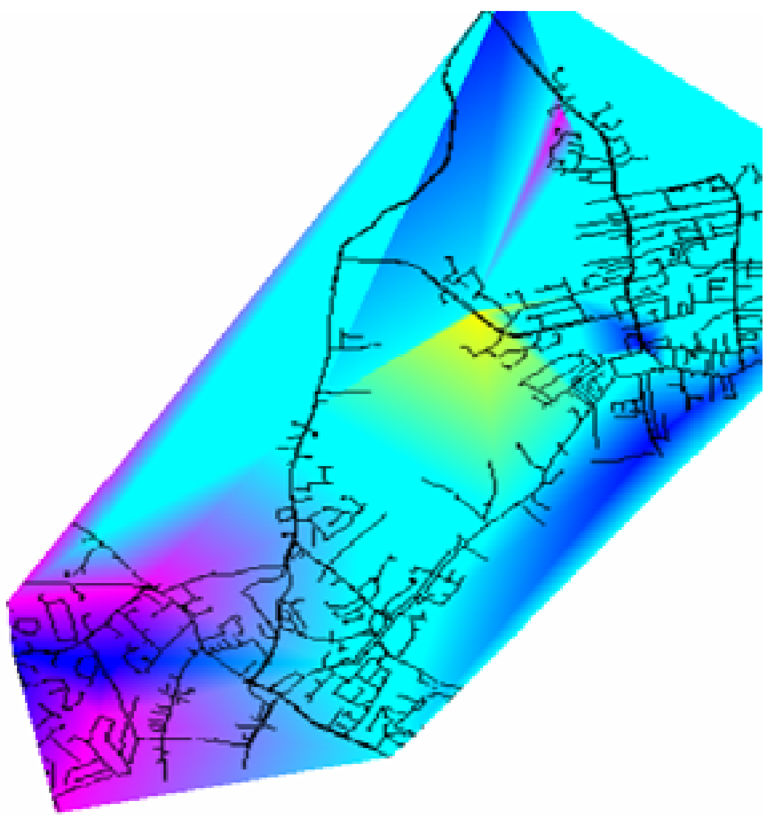
The Kyiv region has a population of well over 4 million people and it is the economic, political and educational center of the Ukraine. In fact, Kyiv was the cradle of all Russian civilization starting with the establishment of the Kievan Rus in the 9$^{th}$ century, from which such aspects of Russian culture as the Cyrillic alphabet and Russian Orthodox Church, but also such cities as Moscow were derived and/or established. Kyiv is a city built on hills and bluffs overlooking the powerful Dnepro (Dnepr) River. As such it has access to a large water supply, but, as with many urban and industrial centers, this river also faces challenges of water pollution. Also, the fact that much of the newer portions of the city are perched on hills and bluffs on both sides of the river and often several hundred meters above the flood plane creates water supply and other engineering challenges. Thus the same issues that caused the builders of the Kyiv subway to make it the deepest in the world (with some stations over 300 meters deep) also make water supply and distribution a challenge.

In order to supply pure water to the region's millions of inhabitants and numerous industries, the Kyivvodokanal (the Kyiv Water Supply and Water Treatment Utility) was established. This organization used both surface and groundwater to supply water needs and maintains an aging system of over 4,000 kilometers of water supply pipes ranging in diameter from 1,400 millimeters to 250 millimeters and 2,500 miles of sanitary sewer lines ranging in diameter from 3,100 millimeters to 200 millimeters. There are also 33 lift stations and a main sewage treatment plant at Bartnytska that uses aerobic treatment prior to discharge of treated wastewater into the Dnepro below Kyiv. There is a separate storm sewer network with 770 kilometers of storm sewers and 1,700 street drains which discharge storm water into the Dnepro at 80 separate points. While most of this vast system, which serves 97.4% of all residences in the Kyiv region, dates to a period since the 1950s and is constructed of ferro-concrete, some parts of the system date to the $19^{th}$ century and are constructed of brick or even of oak! While surface water is supplied by reservoirs upstream on the Dnepro and its major tributaries with protected watersheds, there is also a system of groundwater wells ranging in depth from 298 to 674 feet and taping the middle Jurassic sedimentary aquifer. At the same time it is charged with maintaining this complex network, Kyivvodokanal must deal with the potential for contamination of aquifers with anthropogenic substances and with the protection of groundwater recharge areas. The reservoirs and canals are also part of the system which has to interface with sewage treatment and waste water discharge facilities.

In order to meet these challenges Kyivvodokanal began using different proprietary GIS products in 1994 to map and manage water supply related geospatial data. After initial creation the GIS databases of the engineering networks of the Kyivvodokanal system is now using ESRI technologies for the complex analysis of water and sewer networks and for interface with the municipal GIS databases of the City of Kyiv. This data came from a variety of sources including from engineering drawings (some stored in CAD format including in AutoCAD DWG file format), from existing paper maps, from aerial photography and from to a lesser extent classified remotely sensed imagery. The national GIS data derived from 1:200,000 scale topographic maps is generally at too small a scale to be helpful so 1:2,000 planimetic data on water and sewer line locations and characteristics was overlaid on digitized 1:10,000 topographic maps with the addition of building footprints obtained from 1:2,000 scale town plans obtained from the City government of Kyiv. While the resulting GIS is fairly precise it is not entirely accurate as the newest topographic maps used were generated in 1988 and some are of older vintage. Some newer data from sources such as the City housing Authority has been added to up date building locations and street locations. Also no adequate set of digital elevation model data is currently available so hydraulic modeling is a challenge. This data is now maintained using ArcGIS and ARCVIEW.

Despite limitations in the accuracy and precision of available GIS data layers engineers with Kyivvodokanal in conjunction with researchers at the Kyiv National University of Construction and Architecture have conducted projects to use spatial and network analysis capabilities of ESRI GIS to attempt to determine probable leak sites. An object oriented network model approach utilizing the capability of geo-databases to store behaviors such as flow direction has been developed. This approach is designed to prioritize repair efforts and localized potential locations of leaks. In an aging water supply and sewer network in a city with a fair amount of topographic relief on the banks of a major river, such efforts are necessary. Kyivvodokanal has established an interrelationship with the Kyiv National University of Construction and Architecture which is one of the very few academic institutions in the Ukraine teaching students how to use GIS, specifically ESRI software, as well as basic principles of use of GIS in civil and environmental engineering and urban planning. (Anpilogov, Anpilogov & Kirichenko, 2007).

Figure 5 (below). Part of Kyivvodokanal water distribution network being modeled using ArcGIS Network Analyst.



Some parts of the former Soviet Union and the Ukraine in general and Kyiv in particular have a fine and long tradition of urban and regional planning. The State owning most property in some ways facilitated urban planning. Thus Kyiv has many greenbelt areas and protection of watersheds has also been a consideration historically. However rapid development in recent years in some areas of Kyiv in the absence of coordination of such infrastructure as roads and sewer and water lines poses a challenge. Another uniquely Soviet era challenge carried forward to today and into the foreseeable future is related to the systems of central heating present in most of the former Soviet Union. In these systems hot water was piped from central “warming” plants to heat homes and offices and provides hot water for washing and laundry, etc. Under this system massive blocks of thousands of apartments along with associated schools, shops, and industries would all be heated and provided hot water from a giant central plant using either coal or more recently natural gas to heat the water and send it through a vast network of above ground and underground steam and hot water pipes. While this system has many advantages such as elimination of hot water heaters, and forced air heating (and cooling) and resultant energy savings, it has some major disadvantages as well. These include a monumental “free rider” problem and the need to take the system out of operation periodically. Generally system maintenance can be done over several weeks in the summer (when lack of heat will not be noticed and the inhabitants just bathe in cold water). However, system failures in the winter have forced the evacuation of whole communities in the Ukraine and are in the personal experience of the authors far from unknown. These large central plants are huge users of water and require that low levels of dissolved solids be maintained to prevent scale formation, conversely since most piping is aging iron work water that is too soft would be corrosive further degrading a generally aging system.

It is possible that GIS may be applied to mapping these systems as some time in the future but at present attempts to determine better ways to maintain the system and detect leaks and determine the actual usage of hot water by various users is a huge challenge. There are some possible approaches to managing this difficult problem one is the gradual replacement of the system with other more dispersed hot water and heating methods another is use of some sort of metering devices that could determine hot water usage at multiple locations and using radio frequency cell phone or wireless internet communication links send this data back to managers. Were this approach to develop a large object oriented geospatial database would need to be developed to manage and analyze the vast amount of data generated (Anpilogov & Anpilogov, 2007)

## EXAMPLES OF GIS USE IN OTHER POST- SOVIET STATES

**Russia**: With respect to the Russian Republic, GIS has undergone rapid evolution; mostly in the sphere of the oil and gas industry. There is however an official policy to develop at the federal level, a program for “advanced technologies of cartographic-geodetic” support for the Russian Federation and an official agency charged with this responsibility which is the Federal Service for Geodesy and Cartography of Russia. The following GIS infrastructure projects begun in 1995 are underway in the Russian Federation: creation of a uniform State digital cartographic database, development and enhancement of GIS capabilities and creation of “digital and electronic maps” at scales of 1:200,000 and 1:1,000,000 for the territory of Russia. Considering that 1:25,000 and larger topographic maps existed for the entire territory of the Soviet Union circa 1985, this effort to create digital versions of only the small scale maps seems rather limited in scope. Other digital products that are available from the “ROSGEOINFORM” (Research Centre for Russian Geographic Information) in Moscow include a 1:20,000 digital map of Moscow and a 1:4,000,000 digital map of the entire Russian Republic, as well as a world political map. It would be interesting to compare this with the corresponding 1:1,000,000 scale “Digital Chart of the World” product from the U.S. Defense Departments National Geospatial Intelligence Agency. (Kaminsky & Kotelnikova, 2006). A center for Russian GIS activity is the Department of Cartography and Geoinformatics at Moscow State University which has undertaken a variety of projects such as an effort to create a comprehensive GIS for the Black Sea region (Kotelnikova & Kildyushevskaya, 2007). Other Russian GIS centers include those of the Water Problems Institute of the Russian Academy of Sciences in Moscow which uses ESRI software to map surface and groundwater related issues and the Laboratory of GIS in the Research Institute of Agronomy and Soil Erosion Control which focuses on GIS use in soils mapping and soil conservation and crop science. The particular focus of this institute is the rich Chernozem (blackland or mollisol) soils of the Russian heartland which also extend into the Ukraine and Belorussian Republics and are a vast, if poorly managed storehouse for food production (RRIA&SEC, 2005)

The high level of GIS activity in the oil and gas industry is attributable to this industry being very profitable in recent years, but in a broader sense oil and gas tends today to be a global business with project such as those in the Barets Sea or Sakhalin Island involving "oil majors" like Shell, Exxon, etc, which have large GIS departments and expect their Russian partners to give and receive data is geospatial formats. A good example of a high profile oil and gas project utilizing GIS is the “Blue Stream” project of GAZPROM; Russia’s largest gas producer and hence one of the largest on the planet. This project involves development of a new large diameter high pressure gas pipeline from Russia to Turkey including a substantial undersea portion and thence through export terminals for liquefied natural gas to expanding world markets. This project uses GIS along with pipeline hydraulic calculation software, computer aided design software, risk analysis expert systems, financial analysis software and SCADA software as part of an integrated approach which has generated over 100 gigabytes of geospatial data, much of the development work on this project has been lead by ZAO Intari, Ltd in partnership with GAZPROM and Petergaz (Blinkova, et al. 2007). The activity in oil and gas exploration and production has helped to foster the growth of several GIS related consulting firms notably SOVZOND which specializes in resale and development of classified satellite imagery and works with the major energy companies such as United Energy Systems of Russia, as well as with the Russian Federal Cadastral Agency, the Russian Service for Geodesy and Cartography and the Russian Ministry of Natural Resources.

Another nationwide spatial infrastructure project involves work by the Global Forest Watch Russia an association of 15 non-governmental organizations interested in forest and wilderness preservation and conservation founded in 1999 in Krasnoyarsk. Global Forest Watch Russia has produced a series of GIS based maps using ESRI and ERDAS software of wilderness areas and areas with high conservation values throughout Russia. Their mapping included GIS-based maps of national parks and reserves, forest type, and location of endangered plant and animal species. They use vector-based base maps with national and oblast boundary polygons and major roads and hydrographic features represented by arcs, cities however are only in a point coverage, perhaps indicating that although projects like the one of the Australian initiative mentioned above may have created boundary polygons for Russia's many cities, a point coverage of inhabited places is more appropriate for projects whose main emphasis is on the location and characteristics of forest and wilderness areas. These maps are among the few high resolution GIS-based maps generated in Russia that are readily available on the Internet and are a featured part of this organizations outreach and publicity efforts. (Global Forest Watch, 2006).

**Baltic States**: While the primary emphasis of this paper has been on use of GIS in the Ukraine, a broader perspective that includes the other States of the CIS can be helpful in identifying similarities and differences. All the states of the former Soviet Union have suffered from a lack of GIS development because the historical factors described above. The Baltic States have perhaps made the most rapid progress in implementing GIS. Use by the Land Survey Authority of Latvia beginning as early as 1992 has been mentioned above and indicates the early adoption of GIS there for a task that is only really needed where private ownership of land is present. Private ownership of land is still a somewhat alien concept throughout much of the former Soviet Union today. GIS development work in Latvia has been pioneered by the Department of Geodesy of the Technical University of Riga and by the Laboratory of Astronomy of the University of Latvia which has a lab dedicated to Satellite Geodesy and Geo-Information and a GIS Lab affiliated with the department of Botany and Ecology which has conducted research on ecological issues particularly related to pollution and endangered species in the Baltic Sea. Researchers at these universities have digitized the 1:200,000 scale maps for Latvia (Kalviskis, 2005) .

There is also GIS research and education underway in Estonia and Lithuania primarily at the University of Tartu, and at the University of Technology in Kaunas (Roosaare, 1993). Work on use of GIS in study of wildlife habitat and wildlife passage (primarily of moose) across areas of transportation corridors using ARC/INFO was conducted in 1999 for example (Klein, 2001). Although classified land cover data for Estonia is available at a 1:100,000 scale, other Estonian data is quite detailed and includes 1:6000 scale raster format maps of cities, and 1:10,000 scale data for the entire country. Vector GIS data is also commercially available for Estonia from Regio, Ltd., for urban areas at a scale of 1:2,000 and road data is available from the State Road Agency and address points and address range data is also available. (Ideon, 2006). In Lithuania, there is a joint Lithuanian-Icelandic company called HNIT-Baltic GeoInfo Services Ltd. that is involved in advanced GIS applications has used GIS in preservation and management of natural areas and parks and wetland areas. This same company is deeply involved in using GIS for cellular phone tower location studies taking into account digital elevation model and demand and urban infrastructure data sets (Dereliev, 1999).

**Other European Republics**. Belarus and Moldova are geographically at the edge of the former Soviet Union but are otherwise rather different. Belarus is in many ways a state where the socialist system has worked pretty well. Government ministries and state controlled industry turn out solid products, there has not been a political or economic collapse as in other former Soviet states and mapping activities are basically state supported. GIS is used in Belarus for forest and ecologic and hydrologic mapping. An example of an ecological GIS project in Belarus involved the infamous Chernobyl accident which occurred (as mentioned above) in the Ukraine, but because of prevailing winds in the days immediately after the accident had a disproportionate effect of the nearby Republic of Belarus. Work by Konstatantin Krivoruchko of the Environmental Systems Research Institute in Redlands California has shown that high levels of residual radio-nuclides continue to be present in Belarus. GIS along with various geo-statistical methods were used to assess the environmental fate of these particles of long lived radio isotopes such as cesium 137, strontium 90, plutonium and americium. In particular, kriging of point data to generate regional radioactive risk probability maps indicates that Gomel province is particularly affected (Krivoruchko, 2001). Other work in Belarus related to Chernobyl and sponsored by ESRI and UNESCO include efforts using ESRI’s ARCVIEW software to develop 1:1,000 scale maps of land tenure, land use and radiological monitoring data to assess the economic and environmental impact of Chernobyl in the Pukhovichy district (Goncharova, 2005) as well as detailed mapping of forest reserves using ArcGIS. Moldavia in contrast, though a pleasant bucolic country, seems to not be active in terms of GIS use, although it is not entirely absent from the world technological stage, since it has a reputation of being an Internet piracy, pornography, and virus prorogation center due to a weak central government.

**Caucasian Republics:** The Caucuses are scenic and historically unstable lands with deeply rooted traditions and animosities. Azerbaijan has long been an oil production center and oil and gas GIS is quite active there. After the collapse of the Soviet Union Azerbaijan rebuilt its geospatial (largely satellite image processing) infrastructure. Armenia, a mountainous Christian land which has gone to war with neighboring Muslim Azerbaijan, has had limited GIS but that includes use in the public health sphere in a project funded by the U.S. Agency for International Development. Georgia is one of the most beautiful and bountiful regions of the former Soviet Union, but along with excellent wines and brandy, it produces a bumper crop of assassinations, and on-going insurgencies. The Abkhazian region and the south Ossetia region are in a perpetual state of low grade civil war with the central government. It is however a potential route for oil and gas pipelines and thus of interest to cartographers and GIS analysts working for the oil and gas industry for that reason. Those interested in international terrorism also have reason to map trade routes used for illicit arms and narcotics which often pass through this Republic in their way to and from the Russian Federation.

**Central Asian Republics**: The Central Asian Republics can be differentiated between those like Kazakhstan, Turkmenistan and Uzbekistan that have plentiful oil and gas resources and those that do not. GIS is used extensively on oil and gas related issues in all the Central Asian Republics. One non-energy related issue that has been addressed extensively using geospatial technologies is the receding Aral Sea located in Uzbekistan and Kazakhstan. Much of the effort to map and study this issue using remotely sensed imagery and GIS has been conducted by German researchers supported by German and U.S. sponsors and the United Nations Environment Programe. (Ressl, 2006). Turkmenistan has also used GIS in an effort to delimit the features of another inland sea, in this case the larger Caspian Sea, which in contrast to the Aral Sea is actually rising. Interest in the Caspian Sea focuses on off-shore oil and gas reserves. GIS has been used along with other geospatial technologies and a GIS based software from a Canadian company called CARIS. This software is a Law Of The Sea (LOTS) software solution which is accepted by the United Nations and is being used to help map the boundaries of Turkmenistan's portion of the Caspian Sea to facilitate oil and gas development and limit potential conflicts with other nations that border the Sea, specifically Iran, Kazakhstan, Azerbaijan and Russia (GISUSER, 2007). This is an example of one of many energy related projects in the energy rich Central Asian Republics. Other examples include pipeline corridor analysis and mapping of seismic data, these and other energy related projects are utilizing GIS data and some quite sophisticated applications of a whole panoply of geospatial technologies. In the other Republics of central Asia and in non-energy related spheres of activity one is likely to be only able to obtain very small scale digitized topographic maps that are decades out of date

## CHALLENGES AND OPPORTUNITIES

The disparity between the resources available to support application areas such as petroleum exploration and production in Kazakhstan and lack of even basic current maps (on paper let alone in a digital format) in places like Kirgizstan and Tajikistan, is emblematic of the generally imbalanced character of GIS development and implementation in the Republics of the former Soviet Union. Many entities such as local and regional governments and educational and research entities have only limited access to GIS. For example the Institute of water problems of the Russian Academy of Sciences does have a copy of ARCVIEW, but its numerous researchers lack access to any ArcGIS components or extensions such as ArcHydro, that would extend the limited desktop mapping capabilities available to them. Likewise there is essentially no remapping of the soviet era topographic maps which serve as the basis for most vector based GIS in the

CIS. There are several reasons for this disparity. Foremost is a lack of funding for many societal functions outside the recently booming oil and gas industry.

But that boom is of recent origin; in 1998 the Russian State was in deep financial straights with oil below $20 a barrel. The recent run up in oil prices has tended to "lift all boats" in those post Soviet states that have oil resources, but only a limited amount of that money trickles down to such traditional GIS application areas as infrastructure management, regional planning, ecology, water resources management, etc. The domination of mapping by powerful State authorities (at one time actually the secret police agency itself) and the lack of resources available at a time when this technology was undergoing such rapid evolution in many other countries in North America and Western Europe largely accounts for this disparity.  An example of these State imposed constraints is the prohibition on public use of aerial or space imagery with a resolution higher than 2 meters in the Russian Federation. Likewise use of GPS units with accuracy better than 30 meters is also effectively prohibited for most projects in Russia. There is also a reported lack of books and other training materials related to GIS in the Russian (and even more so in the Ukrainian and other CIS local languages), but there are some magazines related to GIs published in Russian including "GIS Review" and the Bulletin of the Russian GIS Association" (UA Geomatics 2002)

Another important factor is the lack of academic training programs and resources in those programs that do exist. Major universities have made Herculean efforts to maintain brick and mortar facilities along with libraries, map collections, etc, but introduction of new technologies much beyond personal computers has been halting. Thus only two or three Universities in the Ukraine (Kharkiv, Kyiv National University of Construction and Architecture and Taurida National University) have GIS related programs and faculty and likewise two or three Russian universities (such as Moscow State University and the University of Karelia and one Estonian and one Latvian University have specialties in GIS (UA Geomatics, 2002). This in turn means that GIS expertise must be developed by a few specialized companies and in a few large organizations. Many of these organizations are hindered by Byzantine rules for use and release of data that is generated by Russian space and military activities.  Also there is a major problem with use of pirated and virus ridden copies of software. There is also a shortage of Russian language books about GIS. Thus the GIS firms that do exist are relatively small, and somewhat secretive.

A few areas do seem to be active areas of innovation and among those that have the greatest potential to help develop GIS are those in the cell phone and Internet based interactive mapping spheres. Both these technologies have been proliferating rapidly, thus demand for interactive web-based mapping and maps that can be used along with GPS enabled cell phones and other wireless internet mobile devices will likely be strong in the future. A related area of advanced application of GIS is use of spatial analysis and digital elevation model data to select cell phone tower locations. HNIT-Baltic of Latvia is working on this along with such clients as the Russian Beeline and Ukrainian UMC cell phone companies.

In conclusion, the Republics of the former Soviet Union cover a vast area of the planet and have equally vast natural and human resources. More particularly, they have well educated populations and many Republics have extensive oil and gas resources. However, for a variety of largely historical reasons the post-Soviet states have generally lagged the rest of the developed world in GIS adoption. There are many reasons for this, but economic and institutional impediments are a major factor. There are bright spots as well, and there is a huge potential for GIS development if government, industry and the educational spheres of these societies can cooperate. Given the growing diversity of post Soviet states it is likely that such cooperation will occur to a greater degree in some states such as the Baltic ones and less in the Caucasian and Central Asian ones, the future of GIS in Russia and the Ukraine is less certain, but with support from companies like ESRI, and the efforts of leading GIS firms and educational and research institutions like the Russian Academy of Sciences and Kyiv National University of Construction and Architecture and Taurida National Universities, these great counties can be powerful users of geospatial technologies.

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