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A Classification of Ecosystem Desertification Using Satellite Imagery, Dzheltyrbas Gulf, 1980-1989

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A CLASSIFICATION OF ECOSYSTEM DESERTIFICATION USING SATELLITE IMAGERY, DZHILTYRBAS GULF, 1980-1989

by

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A CLASSIFICATION OF ECOSYSTEM DESERTIFICATION USING SATELLITE IMAGERY, DZHILTYRBAS GULF, 1980-1989

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Western Michigan University, 1993

This study focused on the development of a land cover classification method for the Dzhiltyrbas Gulf region southeast of the Aral Sea in the former Soviet Union. Desertification of the region was mapped based on ecosystem descriptions taken from a database defining four stages of desertification. Landsat MSS images (bands 1, 2, and 4) were used as the basis for classification. Standard unsupervised and supervised classification methods did not distinguish the level of detail required to map each stage of desertification in each ecosystem. Therefore, the ecosystems had to be defined and classified as separate entities (based on SBI and GVI), then reintegrated into one image for each year.

The classification method used provided an acceptable landscape categorization, but the method was somewhat tedious. The final map appears to accurately show the distribution of each desertification stage, but the only way to prove or disprove the classification is by ground thruthing the Dzhiltyrbas Gulf region.

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CHAPTER I

INTRODUCTION

Since the early 1960s, the Aral Sea has substantially decreased in area and volume. As it retreats, there is a wide range of effects over many of its adjacent landscapes, particularly over areas adjacent to the former southern shoreline. The main cause of this influence on surrounding landscapes is the diversion of water for irrigation from the Sea's only sources of river inflow: the Amu Dar'ya and Syr Dar'ya. As water is channeled away from these rivers, less reaches the Sea. Due to the arid climate, agriculture in the Aral Sea basin requires irrigation. The more water that has been diverted, the less of an effect the Sea has had on the climate, making the climate somewhat more continental in nature (warmer summers and cooler winters). Precipitation has decreased as well. Dust and salt storms arising from the 30,000 km^2 of salt left on the dried Sea bottom have become a serious problem (Zhu, 1991).

Surrounding landscapes are directly affected by the shrinking Aral Sea in addition to being affected by the many other factors causing the Sea's demise. Primary affects include: changes in ground water levels; increases in salinization of soils; increases of chemicals and pesticides in river water, making it less suitable for human, livestock, and wildlife consumption; and, extreme changes in deltaic ecosystems due to the loss of river waters, as well as many dramatic effects on Sea ecosystems.

The local population suffers a great deal from the effects of Aral Sea recession. For example, drinking water salinity has increased so much that it is causing a very noticeable rise in the number of cases of intestinal disease, throat cancer, and other health problems (Micklin, 1991).

This study will focus on mapping several stages of desertification in Dzhiltyrbas Gulf, a natural landscape formerly connected to the Aral Sea. The information used as a basis for mapping is contained in a database created by Dr. Andrey Ptichnikov of the Institute of Geography in Moscow. The main objective of this study is to develop a method of land cover classification that may be used as a basis for studying desertification in the Aral Sea basin. The study uses IDRISI software (a GIS/image processing package developed by Clark University) to process Landsat digital satellite imagery in order to map the progression of desertification in the Dzhiltyrbas Gulf region.

CHAPTER II

LITERATURE REVIEW

The Aral Sea Problem

The Aral Sea's surface level fell from 53.4 m in 1960 to less than 40 m by 1989. Its area decreased 40%, volume decreased by over 60%, and salinity increased from 10 g/l to 30 g/l (Micklin, 1991). According to Micklin, by 1989 28,000 km^2 of the original sea bottom was no longer covered by the Sea, and large amounts of salts had been deposited there. Some of these salts were taken up into the atmosphere and released back into the Sea. Others were carried and deposited over inland areas in the form of dust storms. Studies have shown that at least 60% of all dust storms have deposited debris in the form of dust and salt over the Amu Dar'ya delta. This seems to add to the need for irrigation, since fresh water is used to flush salts from fields: the more salt deposited, the more water required from the river to flush fields; less water reaches the Sea, the Sea shrinks further, salts are left behind and deposited on fields—in an endless cycle. As salt and dust are deposited, pesticides are also deposited, resulting in the deterioration of pastures and loss of soil fertility (Ashirbekov, 1992). From 1900 to 1980, total irrigation in the basin increased 50%, and by 1989 irrigation increased another 25% (Micklin, 1991). Not only is this irrigation water taken directly from the Amu Dar'ya and Syr Dar'ya, but also from the Kara-Kum canal, the longest canal in the former Soviet Union. None of the water sent along this canal is returned to the Aral Sea. As the sea level drops, so does the ground water table in surrounding areas. A drop of 7-12 m at the coastline has probably affected levels as far away as 170 km from the original shore. This has adversely affected drinking water supplies for communities and has damaged native and cultivated plant species.

The loss of many native plant communities is another drastic change in the basin. Vegetation conditions depend on a number of factors including topography, climate, and both underground and surface water (UNEP, 1991). Many plants are greatly influenced by the presence, absence, and quantity of certain mineral nutrients. The availability of required nutrients can be affected by the pH of the substrate in which the plant thrives (Brooks, 1972).

Phreatophytes, plants which have extensive root systems and depend on obtaining water from the zone of saturation below the water table, grow along riverbanks and deltas (Brooks, 1972). Phreatophytes cannot grow easily in the exposed seabed where there is a lack of fresh water and toxic levels of salinity. In areas where soils have become salinized, salt tolerant and drought tolerant species (halophytes and xerophytes) have developed (Micklin, 1991). The cell walls of halophyte species have a high osmotic pressure, giving them the capacity to hold large amounts of salts. Xerophytes depend on surface rainfall and runoff, so they have shallow root systems (Brooks, 1972).

Another native community, the tugay, which is characterized by lush phreatophytes growing along rivers and around marshes, also has been greatly affected. The total area covered by tugay has been cut in half. Marsh, or hydromorphic, ecosystems have decreased by 700,000 ha, although they still can be found along river and irrigation channels. Both of these communities once thrived partially due to periodic flooding, which flushed salts from deltaic areas. However, flooding has virtually ceased with the Sea's retreat (Micklin, 1991).

As a result of water diversions, the Aral Sea separated into two water bodies in 1987, one small sea to the north and one large sea to the south. The small Aral is fed by the Syr Dar'ya; the large is fed by the Amu Dar'ya. Both seas were connected by a channel until it was blocked in 1992 to keep the water of the northern sea from flowing into the southern sea. Continued large-scale water diversion from the Amu Dar'ya will result in a drop in level of the large Aral to 21 m less than the 1960 level, and the new sea will cover only 34% of its original area by the year 2000. A projected drop to 30 m by 2004 will cause the large Aral sea to separate into a western sea and an eastern sea. The eastern sea would still be supplied by the Amu Dar'ya and the western would continue to shrink (Micklin, 1993).

Background to Current Research

A number of research projects have been implemented in the Aral Sea Basin by local and foreign organizations. The Stockholm Environmental Institute-Boston Center (SEI-B) has developed the Water Evaluation and Planning (WEAP) System, a micro-computer model that simulates future water situations. This model has been used to develop future water management strategies for the Aral Sea basin (Zhu, 1991). Another project has recently been completed by researchers from Russia, the Turkmen Republic and the U.S., comparing the Colorado River basin water resource management requirements with those in the Amu Dar'ya Basin (Micklin, 1992). In addition, scientists at the Institute of Atmospheric Physics in Russia and the U.S. National Oceanic and Atmospheric Administration (NOAA) have been working with scientists in Uzbekistan to study similarities between Aral dust/salt storms and transport of materials from the dried bottom of Owens Lake, California. Also, a study of chemical and biological changes of the Aral Sea is being conducted by the Aral Sea Laboratory of the Zoological Institute in St. Petersburg, Russia. Tree stumps dated to 400 years ago have been discovered along the receding shoreline, indicating that the Aral's surface was once lower and the sea's salinity was once higher than even today

(Micklin, 1992).

The United Nations Environmental Program (UNEP) and the U.N. Development Program (UNDP) have been working with the World Bank to create the Aral Sea Environmental Assistance Plan (ASEAP). The plan was completed in March of 1993 and implemented as a step toward the improvement of economic, social, and physical problems that exist in the Aral Basin. The plan consists of three phases. The first phase will focus on the immediate (emergency) needs of the hardest hit areas. The second and third phases will implement programs to solve long-term problems (World Bank, 1993).

The study addressed in this paper is part of a research project being undertaken by Dr. Philip P. Micklin, Western Michigan University, in conjunction with Dr. Andrey Ptichnikov, Institute of Geography, Russian Academy of Science (Moscow). Their project, funded by the Global Infrastructure Foundation (GIF), Tokyo, involves the establishment of a computer-based GIS to study changes in the Aral Sea Region and is in its early stages of image classification and interpretation of land and water conditions. Later stages of the project will involve larger workstations and larger study areas, with U.S., Russian, Japanese, and German scientists working together with scientists in the Aral Sea basin republics. The areas selected for initial inclusion in the GIS are priority areas, such as wetlands, irrigated land and salinized areas. This study utilized IDRISI software, an inexpensive, but sophisticated, image analysis/GIS package developed by Clark University, Worchester, Massachusetts. Most of the imagery used for analysis were Landsat MSS images (four spectral bands, 79 m spatial resolution).

The objective of this paper is to create a method of image classification (using IDRISI software and Landsat MSS images) that defines changes in the Dzhiltyrbas Gulf region. The classification method developed should be one that can be successfully applied to other Aral Sea landscapes in order to increase the understanding of ecosystem changes associated with the shrinking Aral Sea.

CHAPTER III

DZHILTYRBAS GULF

At one time, Dzhiltyrbas Gulf was connected to the Aral Sea (see Figure 1). The Gulf lies immediately southeast of the Aral's retreating shoreline (see Figure 2, appendix B). As the sea has receded, Dzhiltyrbas Gulf has also been reduced and has undergone significant ecosystem changes. The remnant gulf and its adjacent area is made up of four main ecosystems: (1) dry bottom gulfs with sandy grounds, (2) deltaic interchannel inland depressions, (3) deltaic lake depressions, and (4) deltaic heights--inside and breakthrough deltas and low levees.

Each of these ecosystems has progressively undergone several stages of desertification as the Aral recedes. Each stage of desertification is defined in a database compiled by Dr. Andrey Ptichnikov. Desertification of soils and vegetation depends on a number of factors, the main factor being time. The scale of desertification can depend on a number of natural and man-made (anthropogenic) factors. Climate can greatly affect soil erosion and vegetation degradation, particularly in dry years (Babaev, 1992). Vegetation and soils in the Dzhiltyrbas Gulf area have been greatly affected by desertification as a result of the reduction of the Aral Sea.

The two goals of this study are to map: (1) each of the four main ecosystems within Dzhiltyrbas Gulf; and (2) each stage of desertification within each main ecosystem.

The Database

The data used for classification are from a database compiled by Dr. Andrey

Figure 1. The Aral Sea Basin (Micklin, 1991).

Source: Micklin, Philip P. *The Water Management Crisis in Soviet Central Asia*. The Carl Beck Papers in Russian and East European Studies, no. 905, 1991. Used with permission by Dr. Philip P. Micklin, 7-20-93.

Ptichnikov of the Institute of Geography, Moscow. The information he used to create the database was taken from three main sources:

1. N.M. Novikova, et. al., "A Map of the Modern Vegetation of the Amu-Dar'ya Delta and its Dynamics in Relation to Regulation of River Discharge" (1989);

2. B. Zhollybekov, "Change of the Soil Cover of the Near Aral Portion of the Amu Dar'ya Delta as a Result of Aridization" (1991); and

3. A. Ptichnikov, "Dynamics of Desertification of Landscape in the Aral Sea Region, 1975-1980" (1992).

The database defines each main ecosystem and four stages of desertification for each. Each stage of desertification for each ecosystem is defined by twenty-one characteristics, based on previously mapped data (see Appendix A). The two characteristics most important for mapping ecosystem desertification using digital Landsat MSS images are the vegetation type and the soil type. The characteristics of the four ecosystems examined in this study are described below.

Dry Bottom Gulfs With Sandy Grounds

The dried portion of Dzhiltyrbas Gulf contains areas of both clay and sandy loams of marine and alluvial origin. The depth to ground water ranges from an average 0.4-1.7 m in the first stage of desertification to 3.0-5.0 m in the final stage of desertification.

The initial stage of desertification of dry bottom gulfs with sandy grounds supports a mesophyte halophytic ecosystem (a stage between desertic and wetland) with main species of *Suaeda crassifolia, Salicornia europea* (glasswort), and *Tripolium vulgare*. These are halophytic flora mixed with dead brush found along exposed seabeds taken over by solonchaks (salt encrusted soils). The second phase supports a psammophyte halophytic ecosystem of sand-loving, salt tolerant species (*Attriplex* *fominii* and *Suaeda crassifolia* predominant). Vegetation in the third phase includes *Tamarix hispida, T. ramosissima,* and *Salsola nitraria* in an ecotonic (transitional) psammophytic ecosystem. Finally, a psammophyte desertic ecosystem supports the main vegetation species of black saxaul and white saxaul (*Haloxylon aphyllum* and *H. persicum*).

Soils in the dried gulf area are characteristically salinized throughout each phase, but the level of salinity seems to steadily decrease from high to low, as is characteristic of developing soils in a salt marsh type of environment.

Interchannel Inland Depressions

Interchannel inland depressions have a clay and sandy loam lithology. Ground water level ranges from 0 to 1.5 m in the first stage of desertification down to 5 to 10 m in the final stage. The first stage supports hydrohalophyte reed (*Phragmites australis*) communities. This is succeeded by reeds with halophyte shrubs (*Phragmites australis, Tamarix hispida, Halostachys caspica*). The third phase supports desertified halophyte shrubs and tamarisks (*Tamarix hispida, Halostachys caspica, Salsola dendroides*, with dry *Phragmites australis*). Finally, a desertic hemihalophyte ecosystem supports extremely salt tolerant species including *Haloxylon aphyllum, Anabasis aphylla,* and *Salsola orientalis* .

Originally, inland depressions are characterized by meadow-swampy soils which begin to desiccate in the second stage. By the third stage, wet solonchaks and takyrs have developed, drying and becoming puffy and cracked by the fourth stage.

Deltaic Lake Depressions

The main constituent of deltaic lake depressions is clay loams. Depth to ground water is 0 to 1.5 m initially, but drops to 4 to 10 m in the final stage of desertification.

Generally, desertification of lake depressions follows a pattern similar to interchannel inland depressions.

The initial phase of desertification supports a hydrohalophyte reed ecosystem (*Phragmites australis, Typha angustifolia*). This develops into halophyte shrub and reed communities (*Phragmites australis, Aelopopus litoralis, Tamarix hispida, Halostachys caspica*). Stage three includes mixed ephemerals, or short-lived species (*Senecio subdentatus, Karelinia caspica, Salsola paulsenii*) with reeds along with tamarisk and weeds on the floodplains. Stage three is also characterized by xerohalophyte shrub complexes (*Tamarix hispida, Phragmites australis, Aeloropus litoralis, Halostachys caspica*). Finally, the ecosystem of the fourth stage is characterized by takyrs (clays) with little vegetation. Any existing vegetation is likely to be biurgin (*Anabasis salsa*).

Swampy soils of the first stage desiccate and mix with desiccating meadow soils and wet solonchaks. Solonchaks dry out and takyrs develop in the third stage, becoming desert takyrs by the fourth stage.

It is important to note that both interchannel inland depression and lake depression desertification stages are very similar. Since the areas are characterized by the same type of relief as well as similar desertification stages, they were grouped together for image classification. Henceforth they will be referred to together as "Depressions."

Deltaic Heights and Low Levees

Each stage of deltaic levee desertification is characterized by clay loams and sandy loams. Depth to ground water drops from an average 1.0-3.0 m in the first stage to 5-10 m in the final stage. The first stage supports a fully developed tugay-tamarisk ecosystem with such species as *Populus ariana, Tamarix hispida, Halimodendron* *halodendron*, and *Phragmites australis*. This ecosystem develops into salinized shrub complexes (*Halimodendron halodendron, Tamarix pentandra*) and mixed herb-grass associations (*Aeluropus litoralis, Phragmites australis, Trachonitum scabrun*), with willows (*Salix linearifolia, S. songarica*), oleaster (*Elaeagnus turcomanica*) and poplars appearing as alluvial soils desiccate. Solonchaks with puffy crusts appear in the second stage. The third stage of desertification is characterized by halophyte shrubs, karabarak and tamarisks (*Halostachys caspica, Tamarix hispida*) on puffy crust solonchaks with salinized alluvial-meadow soils. The final stage develops into a desertic hemihalophyte ecosystem supporting black saxaul (*Haloxylon aphyllum*) and eastern saltwort (*Salsola orientalis*) associations on sandy desertic soils with takyrs (clay soils).

Mapping Dzhiltyrbas Gulf Ecosystems

Although these four ecosystems were thoroughly defined in Ptichnikov's database, the stages of desertification had never been mapped for the Dzhiltyrbas Gulf region. In order to do this, the description for each stage of desertification for each ecosystem was assumed to be true. A system of image classification was attempted in which the information from the database was applied to Landsat MSS false color composites using the IDRISI image processing system. Chapter IV describes the classification methods in detail.

CHAPTER IV

METHODS AND METHODOLOGY

A preliminary analysis of the Landsat MSS false color composite images for each year was conducted to understand general landscape trends. In the 1980 composite (7-3-90, #83085105590), vegetation was represented by varying shades of red, areas considered to be dominated by solonchaks were yellow or white, grey areas were most likely sands, and deep water was represented by black. Bright red pixels represented dense reed cover, which was found within Dzhiltyrbas Gulf, along the shoreline, and extending into river channels. Tugay vegetation appeared as dark red pixels following inland river and drainage channels. Areas of differing shades of purples and dark greens probably represented stressed vegetation types. Light green pixels likely represented weeds or herbs in early growth stages.

The 1989 composite (8-16-89, #84258806210) showed a general influx of vegetation growth as the Aral Sea retreated from the Gulf. Bright red pixels represented reeds, as in the 1980 composite, and bright red-orange pixels probably represented new reed growth along the northern channel that once connected the Gulf to the sea. New areas of reeds appeared where shallow Gulf and Sea waters were found in the 1980 composite. The "sand" spits north of the Gulf appeared to be changing (indicated by a mixture of different brightness values than in the 1980 image) possibly due to increased vegetation growth. The areas identified in the 1980 image as "solonchaks" appeared to be changing in a similar manner (differing brightness values were found in those areas).

In the initial stages of classification, an unsupervised classification for each of the 1980 and 1989 composites was conducted, allowing the computer to identify clusters of pixels with similar brightness values (BVs) to assign together as classes. Once the clusters were identified, minor clusters (any classes that were not characterized by homogeneous groups of at least 50 pixels) were reassigned to similar more important clusters to reduce the number of classes. The results were classified according to Ptichnikov's database categories. Both of the unsupervised classifications (1980 and 1989) supported the idea that vegetation was gradually spreading throughout the scene.

A supervised maximum likelihood classification was conducted also (see Figures 3 and 4, Appendix B). Groups of pixels with similar BVs were defined for the computer and the computer classified the image according to these groups. The maximum likelihood classifications contributed to more detailed analyses. For both years, definite areas of tugay could be noted growing along river and drainage channels. By 1989 tugays appeared to dominate the extreme western edge of the image, but according to Ptichnikov's desertification tables, tugays can only be found on levees, not in inland depressions, so the vegetation must have been reed complexes. Reeds spread throughout the depressions between channels and surrounding the Gulf. Halophyte vegetation appeared to be growing on the sand spits to the north of the Gulf. By 1989, solonchaks on the western levee appeared to be mixing with sands, and in other areas solonchaks seemed to be mixing with other soil types or forms of vegetation.

Three important cover types for land cover classification when using satellite imagery include soil, vegetation, and water. To define areas of dry vs. wet soils, a soil brightness index (SBI) was applied to each false color composite. A green vegetation index (GVI) was run in order to define areas of dense, healthy vegetation vs. non-vegetated areas. Also, a non-such index (NSI), which describes the atmospheric noise in an image, was applied to the original scenes (see Figures 5 and 6, Appendix B). The Kauth et al. and Thompson and Wehmanen equations found in Jensen (1986) were adapted by ommitting band 3 to compute these indices as follows:

1. SBI = 0.332MSS1 + 0.603MSS2 + 0.262MSS4.
2. GVI = -0.283MSS1 - 0.660MSS2 + 0.388MSS4.
3. NSI = -0.016MSS1 + 1.131MSS2 + 0.883MSS4.

Pixels characterized by dry soils (such as solonchaks) appeared as higher BVs than wet soils in SBI images. Areas of dense, healthy vegetation appeared brighter than unvegetated areas in GVI images. An interesting result after applying the NSI to the images was that areas of high moisture content (deep waters, marshes) appeared darker than dry areas, repeating the patterns of the SBI images.

Because each resulting image differed greatly in terms of BV range, a linear stretch was run on each, followed by a histogram equalization stretch to give each image the same range of 16 BVs (0-15). Applying both types of stretches to the images was necessary because the GVI images had an extremely wide range of values including negative numbers, and using only one of the techniques did not reduce the number of BVs to 16. The three types of indices were examined individually and then combined into a composite for each year using SBI, GVI, and NSI for the red, green, and blue bands, respectively. The composite, however, was not used for ecosystem classification.

The NDVI (Normalized Difference Vegetation Index) also was calculated using the following default idrisi normalized difference formula and applying MSS bands 4 and 2 appropriately: (Band 4 - Band 2) ÷ (Band 4 + Band 2). An analysis of theNDVI for each year seemed to contradict the idea that vegetation was generally taking over the entire scene by 1989. Solonchaks and sands were becoming more widespread and early stages of vegetation (such as halopyhtes) were emerging over the bare soils.

It is important to note here, although it will be discussed in detail later, that the GVI image showed confusing high BVs, particularly in the Aral Sea and in Dzhiltyrbas Gulf, appearing as though very dense vegetation existed in deep Sea and Gulf water. Inland, lower GVI values showed a nice range of vegetated and unvegetated areas. NDVI BVs, however, lumped lower inland values together, but had distinct high BVs in Sea and Gulf areas.

The results of each brightness index (SBI, GVI, NSI, NDVI) are displayed in Table 1. From the data shown in Table 1, it can be inferred that solonchaks exist where very high SBI and NSI exist with low GVI values (for example on levees). Sands would be indicated by similar GVI levels, but slightly lower SBI and NSI. Reeds are indicated by low SBI, very high GVI and NDVI, and mixed NSI values. Tugays would be similar to reeds, but slightly lower in GVI and NDVI. Overall, the data show that the dry sea bed areas have dry or salinized soils and low amounts of vegetation; levees support dry or salinized soils and low amounts of vegetation; inland depressions support wet soils and high amounts of vegetation; lake depressions support moderately wet soils and some lush vegetation on the Gulf shoreline. Extremely lush vegetation (reeds) in shallow Gulf waters are supported by lake depressions also.

An overlay of the SBI image plus the GVI and NDVI images was created in order to familiarize the analyst with the area based on combinations of soil and vegetation reflectances (see Figures 7 and 8, Appendix B). This step was designed to rule out possibilities of certain plant or soil types existing in some locations. A combination of high SBI and low GVI/NDVI, for example, would eliminate Depression stages I and II or Levee stages I and II since those stages are all characterized by lush vegetation and marshy (wet) soils. An outline of this procedure is located in Appendix C.

To create this SBI/GVI/NDVI image, both soils and vegetation were reclassed

Table 1

A Comparison of Brightness Indices
for Dzhiltyrbas Gulf 1980 & 1989*

1980				
Index	Dry Bottom	Levees	Inland Depressions	Lake Depressions
SBI	mixed mid to high	very high	mid to low	low to mid
GVI	mid	low to mid (very low in NE area)	mid	mid to high
NSI	mid to high (lower on newly exposed seabed)	very high	mid to low	low to mid
NDVI	scattered mid to high along shoreline	scattered mid to high	high	high

1989				
Index	Dry Bottom	Levees	Inland Depressions	Lake Depressions
SBI	mid to high	high	low	low
GVI	low	low to mid	high	mid along shoreline to high in gulf
NSI	low to mid	high	low to mid	very low
NDVI	mid	mid	high	high

* Brightness values were classed into 3 categories: 1-4 equals low, 5-10 equals mid, 11-15 equals high.

into three classes of low, mid, and high reflectances. For the SBI, values 1-4 were considered low (class 1), values 5-10 mid (class 2), and 11-15 high (class 3). The vegetation was reclassed using the GVI values 1-4 as low (1), and 5-10 as mid (2). As discussed above, NDVI values 14 and 15 were used to define high GVI (3).

Each of the desired SBI BV classes 1, 2 and 3 were reclassed as individual images, then overlayed one at a time (e.g., low SBI + mid SBI + high SBI) to be sure there was no overlap between classes. If there was any overlap between classes, more than just three classes would appear on the class 1 + class 2 + class 3 overlay. For example, if class 1 overlapped with class 3, a new class 4 would result, (1 + 3 = 4).

The same type of combination of the low and mid GVI BVs and the high NDVI BVs was used to create a new GVI image. Some overlap was found in the mid and high BVs, and these areas were reclassed as high (GVI class 3), because high vegetation was considered dominant in this case.

In order to overlay the SBI and GVI images and have no overlap of value combination, each image was weighted. For example, if values 1, 2, and 3 were used for low, mid and high classes of each image and a new value of 4 was found on the resulting overlay image, the 4 could mean any of the following combinations of soils and vegetation:

1. Low SBI (1) + High GVI (3) = 4.
2. Mid SBI (2) + Mid GVI (2) = 4.
3. High SBI (3) + Low GVI (1) = 4.

To avoid this problem, and to be able to identify which BV represented which SBI/GVI combination, each image was multiplied by a constant; in this case the SBI image was multiplied by 3 and the GVI image by 14. The new values were computed as: original class x weight = new class. Specifically,

1. SBI Low = 1 x 3 = 3.

2. SBI Mid = 2 x 3 = 6.
3. SBI High = 3 x 3 = 9.
4. GVI Low = 1 x 14 = 14.
5. GVI Mid = 2 x 14 = 26.
6. GVI High = 3 x 14 = 42.

The resulting image could have had a total of 9 combinations of SBI/GVI, as well as six areas that may have had only one of the three SBI values and no GVI overlapping them, or one of the three GVI values and no SBI overlap. In other words, if the SBI values equalled zero the GVI value for that pixel was assigned. Those pixels falling within the image area (not in the background) with a value of zero were designated as deep water. This meant that a total of 16 classes were possible on the SBI/GVI image as shown in Table 2 .

These numbers were than reclassed from 0-15 into the final SBI/GVI image. Four combinations were not found in the 1980 image: low SBI, mid SBI, low SBI + low GVI, and mid SBI + low GVI. Three weren't found in the 1989 image: low SBI, mid SBI, and low SBI + low GVI. Areas that were obviously part of the sea in the 1980 image, but reflected as mid or high GVI values, may have appeared this way due to reflectance from the sea bottom in shallow areas.

The 1980 and 1989 SBI/GVI images were than compared to Ptichnikov's desertification database to map the locations of each stage of desertification for each ecosystem. First, an area defining "dry bottom" was defined. Dry bottom areas were easily identifiable on the false color composites. Dry bottom areas can only exist in former sea beds, which were identified by the outline of the former coastline in the northwestern area of the 1980 image. To delineate the dry bottom on the 1989 image, the area covered by the Aral Sea in 1980 was compared to the area covered in 1989. Since Dzhiltyrbas Gulf was still connected to the Aral Sea in 1980, the difference in

Table 2

Possible SBI/GVI Combinations and Brightness Values

Class (es) = BV	Final BV
Water = 0	0
Low SBI = 3	1
Mid SBI = 6	2
High SBI = 9	3
Low GVI = 14	4
Mid GVI = 28	5
High GVI = 42	6
Low SBI + Low GVI = 17	7
Low SBI + Mid GVI = 31	8
Low SBI + High GVI = 45	9
Mid SBI + Low GVI = 20	10
Mid SBI + Mid GVI = 34	11
Mid SBI + High GVI = 48	12
High SBI + Low GVI = 23	13
High SBI + Mid GVI = 37	14
High SBI + High GVI = 51	15

comparative area between 1980 and 1989 was used to delineate "dry bottom" in 1989, and helped to define the 1980 dry bottom gulfs.

Next, vector files outlining the dry bottom area for each year were digitized onscreen using the 1980 and 1989 false color composites. The vector file polygons were then rasterized and transferred to new (blank) image files. The polygons were assigned a value (20) higher than the highest value of the SBI/GVI images (15) and overlaid (added) with the original images. The only resulting values that weren't in the areas of depressions or levees for both years were values 25, 31, 33, and 34 (original values of 5, 11, 13, and 14 on the SBI/GVI images). These were then reclassed, in order, as 1-4 to define the location of each stage of dry bottom desertification.

The polygon used to define the dry bottom area was reclassed out of the original image by assigning any value over 15 to zero, so that any overlap between dry bottom and levee polygons wouldn't be classified in both dry bottom and levee desertification stages.

The same procedure as above was followed for levees, but levee polygons were overlaid with the original SBI/GVI image minus the area defining the dry bottom polygon. This time, two polygons were used to define the levee areas for each year. When each of these polygons was assigned as BV 20 and overlaid with the original minus dry bottom area, the only values shown that weren't in depressions but were on the levees, were 31-34. These were reclassed as 1-4, respectively (originally 11, 12, 13, and 14). The areas defining levee polygons were cut from the original images as well, so all that remained of the original SBI/GVI images were unclassified depressions.

Depressions (interchannel inland depressions grouped with lake depressions) were easily mapped from the original images minus dry bottom and levee areas, with no need for digitizing. Areas represented by BV 9 were found in the same areas as dense reeds growing in the Gulf as shown in the false color composites, so BV 9 was reclassed as depression stage 1. BV 12 was reclassed as 2, 11 as 3, and 15 as 4.

To create the final fully classified desertification stage image, the classified areas of dry bottom, levees, and depressions were overlaid to create images for each year referred to as 80CLASSD and 89CLASSD. Each BV in these images was reclassed to

16, and then overlaid with the original SBI/GVI images. Each value over 15 in the resulting images was then reclassed to zero in order to identify those areas that still remained unclassified (for example, some areas of depressions had to be included in the dry bottom polygons but weren't classified because they weren't dry bottom). These images, referred to as 80UNAREA and 89UNAREA, were reclassed to match the BVs in the 80/89CLASSD images. Pixels in the 80/89UNAREA images were examined onscreen and assigned to the appropriate classes according to brightness value and location. The two "CLASSD" images and the newly classified "UNAREA" images were overlaid and classified into the following classes: dry bottom desertification stages 1-4, levee stages 1-4, and depressions 1-4.

The final images for 1980 and 1989 portrayed the location and extent of each stage of desertification for each ecosystem in the Dzhiltyrbas Gulf region (see Figures 9 and 10, Appendix B). The area covered by each class is shown in Table 3.

Table 3

Change in Area (km^2)

Class	1980 km^2	1989 km^2	Change (+/- km^2)
Deep Water	659.4	438.6	- 220.8
Dry Bottom 1	77.4	216.0	+ 138.6
Dry Bottom 2	403.4	211.8	- 191.6
Dry Bottom 3	24.1	269.1	+ 245.0
Dry Bottom 4	264.1	357.4	+ 93.3
Levees 1	61.1	184.7	+ 123.6
Levees 2	713.4	212.0	- 501.4
Levees 3	515.2	539.8	+ 24.6
Levees 4	744.5	949.5	+ 205.0
Depressions 1	504.8	613.6	+ 108.8
Depressions 2	208.1	150.1	- 58.0
Depressions 3	316.6	478.7	+ 162.1
Depressions 4	2.0	25.4	+ 23.4

CHAPTER V

CONCLUSIONS

Results of an analysis of the final 1980 and 1989 classified desertification stage images are summarized in Table 4. In a comparison of the 1980 and 1989 SBI/GVI images, a general trend could be seen particularly well as the Aral Sea receded. Soils dried out rather quickly as they became more vegetated. The depressions surrounding Dzhiltyrbas Gulf appeared to have become less vegetated even though they seemed to remain wet. This could have been related to a drop in the ground water table. Another possibility may be that 1989 was a considerably wet year in comparison to 1980.

Overall, vegetation decreased inland, yet initial growth of colonizing halophytes were established quickly on the dried seabed. Reeds, however, spread northward through the channels formerly connecting the Gulf to the Sea. This may have been a result of the drop in the water's surface level, which became shallow enough for reeds to take root, yet still had plenty of water for them to thrive.

An analysis of the results of the final desertification classification for each year showed the classifications to be quite acceptable, fulfilling the research objectives adequately. However, the methods proved to be quite tedious and could easily be improved. Although the final desertification images appear to have accurately mapped each desertification stage described in Ptichnikov's database, the only way to determine the level of accuracy is by ground truthing in the Dzhiltyrbas region.

The use of this particular method of desertification classification should contribute to the development of other methods of ecosystem classification in the Aral Sea basin. Applying elevation data or other topographic data to the imagery could lead

Table 4

Location of Dzhiltyrbas Desertification Stages
1980 & 1989

1980 Dry Bottom

Stage I: found around shallow shoreline depressions and scattered on shoreline

Stage II: widespread on western shores and on the perimeters of peninsulas at north of gulf

Stage III: scattered with stage IV

Stage IV: heavy on peninsulas; scattered along western shore

1989 Dry Bottom

Stage I: much in the northwestern part of the image, scattered elsewhere indicating wetter areas

Stage II: mixed well with stage I

Stage III: much on the shoreline and spreading from the peninsulas

Stage IV: much in the old seabed (mixed with stage III); scattered on perimeters

1980 Levees

Stage I: along river channel on western levee; some in depressions on eastern levee and on eastern shoreline of gulf (very minimal)

Stage II: much in eastern depressions; some on shoreline of eastern levee; much on the slopes of the western levee and into western depressions

Stage III: scattered on western levee; very concentrated on eastern levee, particularly on the northern half of it

Stage IV: much on western levee, indicating highest elevations; along area associated with stage II on eastern shoreline; much on the southern half of the eastern levee

1989 Levees

Stage I: scattered on western levee; shows up in areas on eastern levee that are becoming wetter as gulf/water shifts location

Stage II: shows an extreme change; now only along west coast of gulf and partially on the northeastern area of western levee; some in depressions

Table 4—Continued

Stage III: still most on northern half of eastern levee; follows river and scattered on western levee

Stage IV: scattered more widely, particularly on western levee and southern half of eastern levee; into depressions and along gulf shoreline

1980 Depressions

Stage I: most concentrated in gulf and along river channels and inland lakes

Stage II: most in southwest along river drainage depressions and on either side of central gulf; along northern reaches of the middle channel extending north from gulf; some in extreme western depression

Stage III: most in extreme western and southwestern depressions, into western gulf coast; some in eastern depressions; overall, dispersed fairly well throughout depressions

Stage IV: very small area on eastern peninsula jutting into central gulf

1989 Depressions

Stage I: most concentrated in gulf, but less in the southern gulf as water is diverted; much in northeastern channel formerly connecting gulf to sea; much in western river channels and western depressions; some in western newly exposed seabed

Stage II: still much in southwestern depressions; more in north central gulf bay area; some with stage I in western newly exposed sea bed; less surrounding gulf overall

Stage III: much still in southwestern depressions; more in depressions through eastern levee; some along eastern edge of northeastern channel

Stage IV: a bit more along newly exposed seabed of northern channels and surrounding them; some (minimal) in southeastern gulf where water is draining into depressions

to the development of a more simplified classification strategy. Precipitation levels or other climatic factors are also important when studying changes in desertification. Once a permanent method of classification is established, prediction models of Aral Sea basin desertification may be constructed. The method should then be applied to other Aral Sea regions.

The results of this study are not to be considered conclusive. They are only a part of the much larger Aral Sea region research being conducted by Dr. Philip Micklin and Dr. Andrey Ptichnikov.

Appendix A

Detailed Descriptions of Dzhiltyrbas Gulf Ecosystems

Description of Dry Bottom Gulfs with Sandy Ground
Dzhiltyrbas Gulf
Phase I of IV

Relief	Flat, dry gulf
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Marine and alluvial
Main Geomorphologic Processes	Desiccation, salinization
Character Forms of Relief	-----
Depth to Ground Water Level (m)	0.4 - 1.7
Ground Water Mineralization (g/l)	20 - 30
Type of Soil	Marine sands, moderately to strongly salinized
Concentration of Salts (%)	0.3 - 0.9
Composition of Salts	Cl - SO_4
pH	-----
Humus (%)	-----
Type of Ecosystem	Mesophytic halophytes
Main Species	*Suaeda crassifolia, Salicornia Europea, Tripolium vulgare*
Density of Vegetation Cover (%)	20 - 30
Character Time of Existance	2 - 5 years
Landuse	None

Description of Dry Bottom Gulfs with Sandy Ground
Dzhiltyrbas Gulf
Phase II of IV

Relief	Flat, dry gulf
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Marine and alluvial
Main Geomorphologic Processes	Desiccation, strong deflation, suffosion, desalinization
Character Forms of Relief	Phytogenic hillocks and ridges
Depth to Ground Water Level (m)	1.7 - 2.5
Ground Water Mineralization (g/l)	15 - 25
Type of Soil	Marine sands, moderately to strongly salinized
Concentration of Salts up to 1 m (%)	0.9 - 1.6
Composition of Salts	$Cl - SO_4$
pH	8.4 - 9.1
Humus (%)	0.4 - 0.9
Type of Ecosystem	Psammophytic halophyte
Main Species	*Attriplex fominii, Suaeda crassifolia*
Density of Vegetation Cover (%)	10 - 20
Character Time of Existance	1 - 9 years
Landuse	None

Description of Dry Bottom Gulfs with Sandy Ground
Dzhiltyrbas Gulf
Phase III of IV

Relief	Flat; dry gulf
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Marine and alluvial
Main Geomorphologic Processes	Desiccation, strong deflation, suffosion, desalinization
Character Forms of Relief	Phytogenic hillocks, ridges, dunes
Depth to Ground Water Level (m)	2.5 - 3.5
Ground Water Mineralization (g/l)	30 - 40
Type of Soil	Marine sands, moderately to low salinized
Concentration of Salts (%)	0.4 - 0.9
Composition of Salts	Mixed
pH	7.4 - 9.5
Humus (%)	0.1 - 0.3
Type of Ecosystem	Ecotonic psammophyte
Main Species	*Tamarix hispida, T. ramosissima, Salsola nitraria*
Density of Vegetation Cover (%)	15 - 30
Character Time of Existance	6 - 15 years
Landuse	None

Description of Dry Bottom Gulfs with Sandy Ground
Dzhiltyrbas Gulf
Phase IV of IV

Relief	Flat, dry gulf
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Marine and alluvial
Main Geomorphologic Processes	Deflation, eolic processes
Character Forms of Relief	Dunes and ridges
Depth to Ground Water Level (m)	3.0 - 5.0
Ground Water Mineralization (g/l)	-----
Type of Soil	Sandy low to moderately salinized
Concentration of Salts (%) to 1 m	0.1 - 0.9
Composition of Salts	Mixed
pH	7.4 - 9.5
Humus (%)	0.4 - 1.5
Type of Ecosystem	Psammophyte desertic
Main Species	*Haloxylon aphyllum, H. persicum, Carex physodes*
Density of Vegetation Cover (%)	5 - 30
Character Time of Existance	Hundreds
Landuse	None

Description of Deltaic Interchannel Inland Depressions
Dzhiltyrbas Gulf
Phase I of IV

Relief	Smooth depressions or flat plains
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization
Character Forms of Relief	-----
Depth to Ground Water Level (m)	0.0 - 1.5
Ground Water Mineralization (g/l)	0.2 - 3.0
Type of Soil	Meadow-swampy
Concentration of Salts (%)	0.2 - 1.0
Composition of Salts	Cl - SO_4, Cl
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Hydrohalophyte reed
Main Species	*Phragmites australis*
Density of Vegetation Cover (%)	60 - 90
Character Time of Existance	5 - ? years
Landuse	Grazing, hunting, fishing, reed harvest

Description of Deltaic Interchannel Inland Depressions
Dzhiltyrbas Gulf
Phase II of IV

Relief	Smooth depressions or flat plains
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization
Character Forms of Relief	Phytogenic hillocks up to 1 m high
Depth to Ground Water Level (m)	1.5 - 3.0
Ground Water Mineralization (g/l)	0.4 - 2.5
Type of Soil	Desiccating meadow-swampy
Concentration of Salts (%)	1.0 - 2.0
Composition of Salts	Cl—SO_4
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Reeds with halophyte shrubs
Main Species	*Phragmites australis* , *Tamarix hispida*, *Halostachys caspica*
Density of Vegetation Cover (%)	40 - 70
Character Time of Existance	5 - ? years
Landuse	Grazing, reed harvest

Description of Deltaic Interchannel Inland Depressions
Dzhiltyrbas Gulf
Phase III of IV

Relief	Smooth depressions or flat plains
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization, deflation
Character Forms of Relief	Phytogenic hillocks up to 1 m high
Depth to Ground Water Level (m)	3.0 - 5.0
Ground Water Mineralization (g/l)	8.0 - 20.0
Type of Soil	Wet or takyric solonchaks
Concentration of Salts (%)	2.0 - 4.0
Composition of Salts	Cl - SO_4
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Desertified halophyte shrubs
Main Species	*Tamarix hispida, Halostachys caspica, Salsola dendroides* with dry *Phragmites australis*
Density of Vegetation Cover (%)	10 - 30
Character Time of Existance	5 - ? years
Landuse	?None?

Description of Deltaic Interchannel Inland Depressions
Dzhiltyrbas Gulf
Phase IV of IV

Relief	Smooth depressions or flat plains
Lithology of Deposits	Clay loams, sandy loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Deflation, eolic processes
Character Forms of Relief	Bold takyrs and microdunes
Depth to Ground Water Level (m)	5.0 - 10.0
Ground Water Mineralization (g/l)	8.0 - 20.0
Type of Soil	Takyric or puffy desertic solonchaks
Concentration of Salts (%)	2.0 - 5.0
Composition of Salts	Cl - SO_4
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Desertic hemihalophytic
Main Species	*Haloxylon aphyllum, Anabasis aphylla, Salsola orientalis*
Density of Vegetation Cover (%)	10 - 30
Character Time of Existance	Hundreds of years
Landuse	?None?

Description of Deltaic Lake Depressions
Dzhiltyrbas Gulf
Phase I of IV

Relief	Smooth depressions or lowlands
Lithology of Deposits	Clay loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization
Character Forms of Relief	Small lake terraces
Depth to Ground Water Level (m)	0 - 1.5
Ground Water Mineralization (g/l)	1.0 - 9.0
Type of Soil	Swampy
Concentration of Salts (%)	0.5 - 1.0
Composition of Salts	Cl - SO_4, Cl
pH	5.0 - ?
Humus (%)	1.0 - 3.0
Type of Ecosystem	Hydrohalophyte reeds
Main Species	*Phragmites australis, Typha angustifolia*
Density of Vegetation Cover (%)	60 - 100
Character Time of Existance	5 - ? years
Landuse	Grazing, reed harvest, hunting, fishing, protected reserves

Description of Deltaic Lake Depressions
Dzhiltyrbas Gulf
Phase II of IV

Relief	Smooth depressions or lowlands
Lithology of Deposits	Clay loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization, microfaulting of ground
Character Forms of Relief	Small lake terraces
Depth to Ground Water Level (m)	1.5 - 3.5
Ground Water Mineralization (g/l)	7.0 - 20.0
Type of Soil	Desiccating meadow-swampy, wet solonchaks
Concentration of Salts (%)	1.5 - 3.5
Composition of Salts	SO_4
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Halophyte shrubs and reeds
Main Species	*Phragmites australis, Aeluropus litoralis, Tamarix hispida, Halostachys caspica*
Density of Vegetation Cover (%)	40 - 70
Character Time of Existance	5 - ? years
Landuse	Grazing, reed harvest, hunting

Description of Deltaic Lake Depressions
Dzhiltyrbas Gulf
Phase III of IV

Relief	Smooth depressions or lowlands
Lithology of Deposits	Clay loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization, deflation
Character Forms of Relief	Small lake terraces, phytogenic hillocks
Depth to Ground Water Level (m)	3.5 - 5.0
Ground Water Mineralization (g/l)	30.0 - 50.0
Type of Soil	Puffy and takyric solonchak crusts
Concentration of Salts (%)	3.0 - 8.0
Composition of Salts	SO_4
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Xerohalophyte shrubs
Main Species	*Tamarix hispida, Phragmites australis, Aeloropus litoralis, Halostachys caspica*
Density of Vegetation Cover (%)	5 - 20
Character Time of Existance	5 - ? years
Landuse	?None?

Description of Deltaic Lake Depressions
Dzhiltyrbas Gulf
Phase IV of IV

Relief	Smooth depressions or lowlands
Lithology of Deposits	Clay loams
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, deflation, eolic processes
Character Forms of Relief	Barren takyrs
Depth to Ground Water Level (m)	4.0 - 10.0
Ground Water Mineralization (g/l)	25.0 - 50.0
Type of Soil	Takyrs or desertic takyrs
Concentration of Salts (%)	2.0 - 8.0
Composition of Salts	SO_4
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Unvegetated takyrs
Main Species	None, or possibly *Anabasis salsa*
Density of Vegetation Cover (%)	0 - 5
Character Time of Existance	Hundreds of years
Landuse	?None?

Description of Deltaic Heights, Inside and Breakthrough Levees
Dzhiltyrbas Gulf
Phase I of IV

Relief	Flat plain
Lithology of Deposits	Clay loams, sandy loams, sands
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization
Character Forms of Relief	Smooth terraces, cones, low levees
Depth to Ground Water Level (m)	1.0 - 3.0
Ground Water Mineralization (g/l)	1.0 - 3.0
Type of Soil	Alluvial-meadow with wet solonchaks
Concentration of Salts (%)	0.2 - 1.5
Composition of Salts	Cl - SO_4, NaCl
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Fully developed tugay-tamarisk complexes
Main Species	*Populus ariana, Tamarix hispida, Halimodendron halodendron, Phragmites australis*
Density of Vegetation Cover (%)	60 - 90
Character Time of Existance	5 - ? years
Landuse	Grazing, logging

Description of Deltaic Heights, Inside and Breakthrough Levees
Dzhiltyrbas Gulf
Phase II of IV

Relief	Flat plains
Lithology of Deposits	Clay loams, sandy loams, sands
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization
Character Forms of Relief	Smooth terraces, cones, low levees
Depth to Ground Water Level (m)	1.5 - 3.0
Ground Water Mineralization (g/l)	2.0 - 5.0
Type of Soil	Desiccating alluvial-meadow with solonchak crusts
Concentration of Salts (%)	1.0 - 5.0
Composition of Salts	Cl - SO_4
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Salinized tugay shrub complexes
Main Species	*Tamarix hispida, T. laxa, Halostachys caspica*
Density of Vegetation Cover (%)	20 - 60
Character Time of Existance	5 - ? years
Landuse	Grazing, logging

Description of Deltaic Heights, Inside and Breakthrough Levees
Dzhiltyrbas Gulf
Phase III of IV

Relief	Flat plains
Lithology of Deposits	Clay loams, sandy loams, sands
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Desiccation, salinization, strong deflation
Character Forms of Relief	Smooth terraces, cones, low levees, microdunes
Depth to Ground Water Level (m)	3.0 - 5.0
Ground Water Mineralization (g/l)	6.0 - 30.0
Type of Soil	Salinized alluvial-meadow with solonchak crusts
Concentration of Salts (%)	4.0 - 9.0
Composition of Salts	$Cl - SO_4$
pH	-----
Humus (%)	1.0 - 3.0
Type of Ecosystem	Halophyte shrubs
Main Species	*Halostachys caspica, Tamarix hispida*
Density of Vegetation Cover (%)	10 - 20
Character Time of Existance	5 - ? years
Landuse	?None?

Description of Deltaic Heights, Inside and Breakthrough Levees
Dzhiltyrbas Gulf
Phase IV of IV

Relief	Flat plains
Lithology of Deposits	Clay loams, sandy loams, sands
Genesis of Deposits	Alluvial
Main Geomorphologic Processes	Strong deflation, eolic processes
Character Forms of Relief	Smooth sandy cones, microdunes, ridges
Depth to Ground Water Level (m)	5.0 - 10.0
Ground Water Mineralization (g/l)	10.0 - 30.0
Type of Soil	Sandy desertic with takyrs
Concentration of Salts (%)	2.0 - 6.0
Composition of Salts	Cl - SO_4
pH	-----
Humus (%)	0.8 - 2.0
Type of Ecosystem	Desertic hemihalophyte
Main Species	*Haloxylon aphyllum, Tamarix hispida, Halostachis caspica*
Density of Vegetation Cover (%)	10 - 20
Character Time of Existance	Hundreds of years
Landuse	?None? (?grazing, road construction?)

Appendix B

Imagery

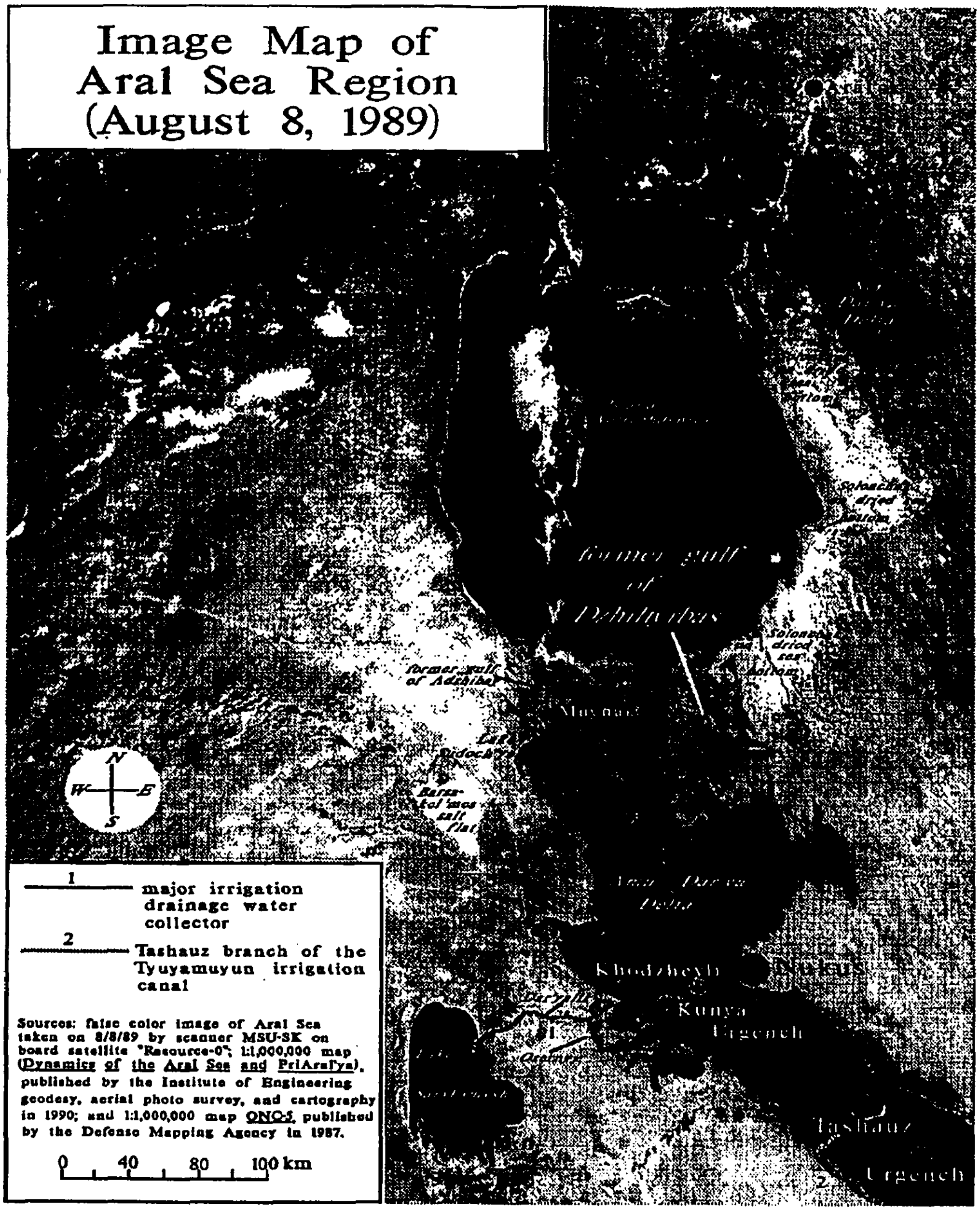

Figure 2. Image Map of the Aral Sea, August 8, 1989.

Source: Micklin, Philip P. *The Water Management Crisis in Soviet Central Asia.* The Carl Beck Papers in Russian and East European Studies, no. 905, 1991. Used with permission by Dr. Philip P. Micklin, 7-20-93.

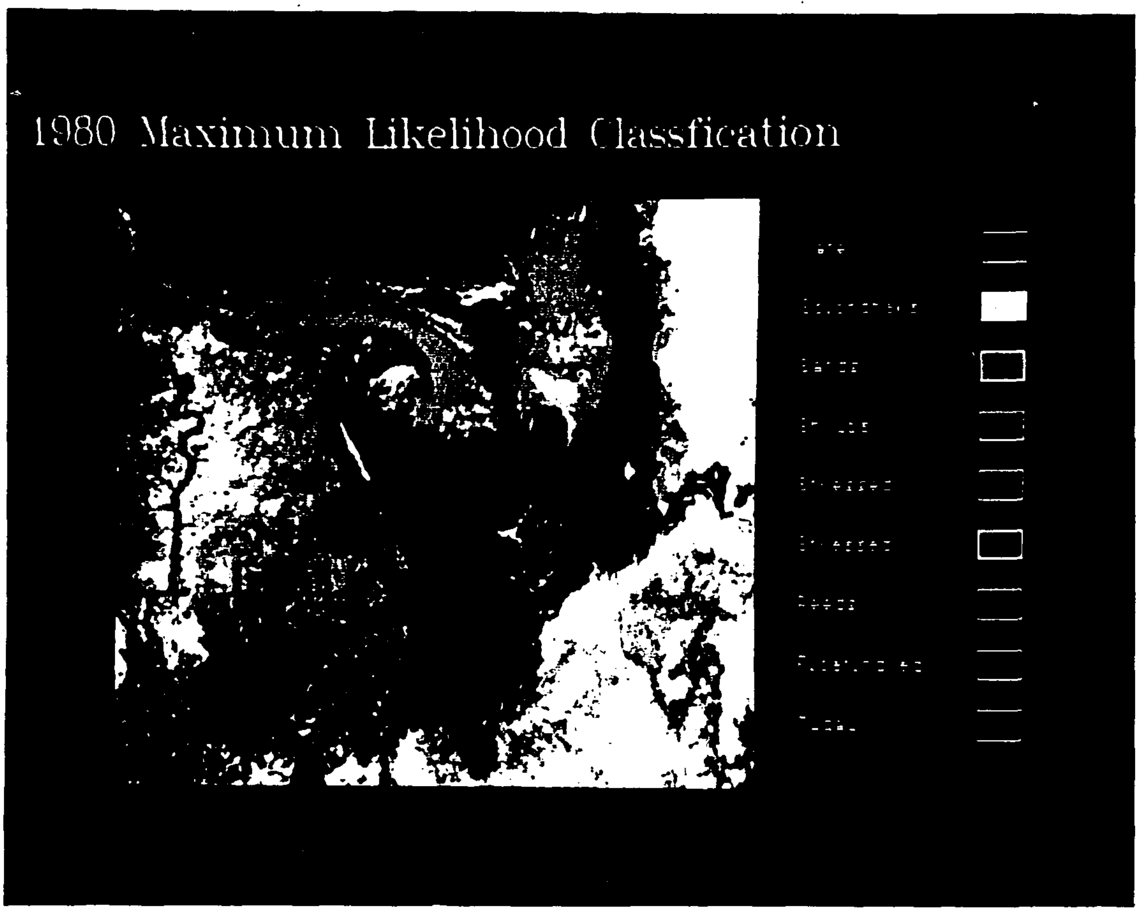

Figure 3. 1980 Maximum Likelihood Classification.

Figure 4. 1989 Maximum Likelihood Classification.

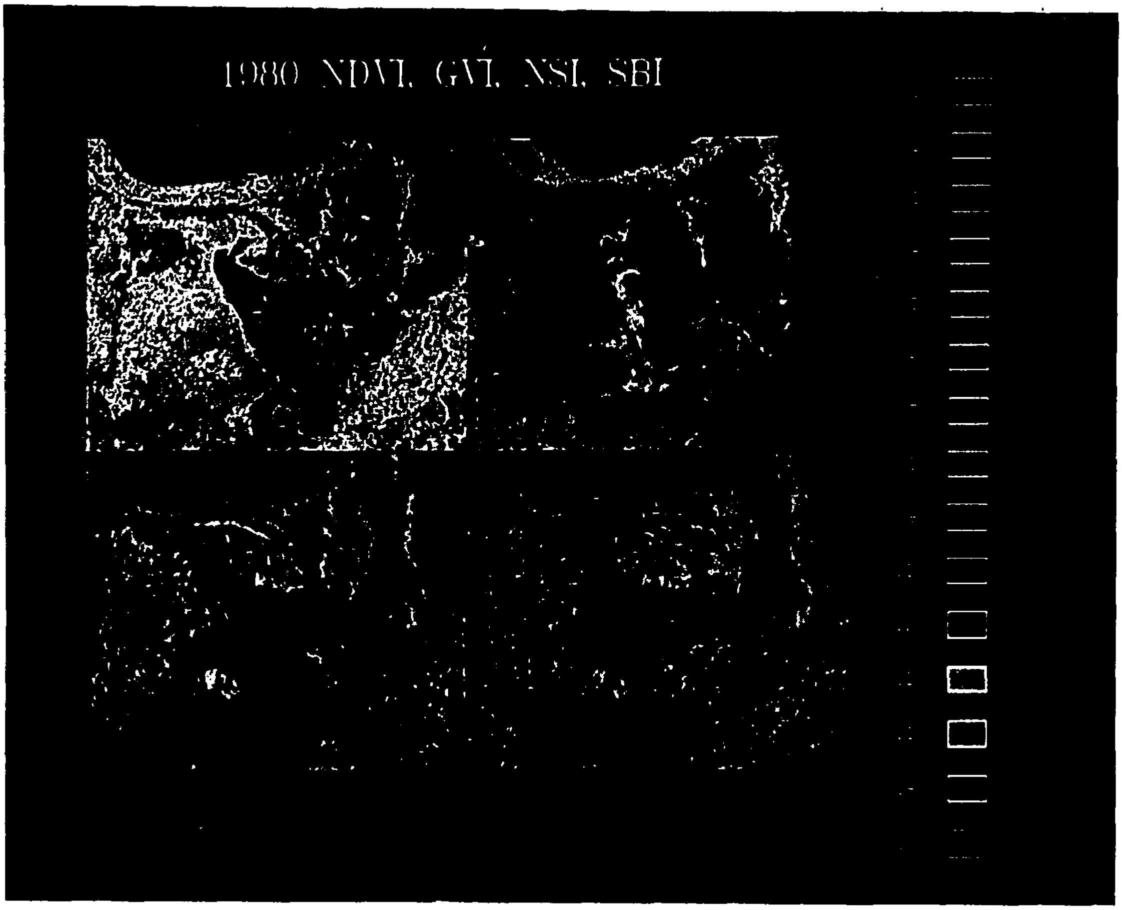

Figure 5. 1980 NDVI, GVI, NSI, SBI Classifications.

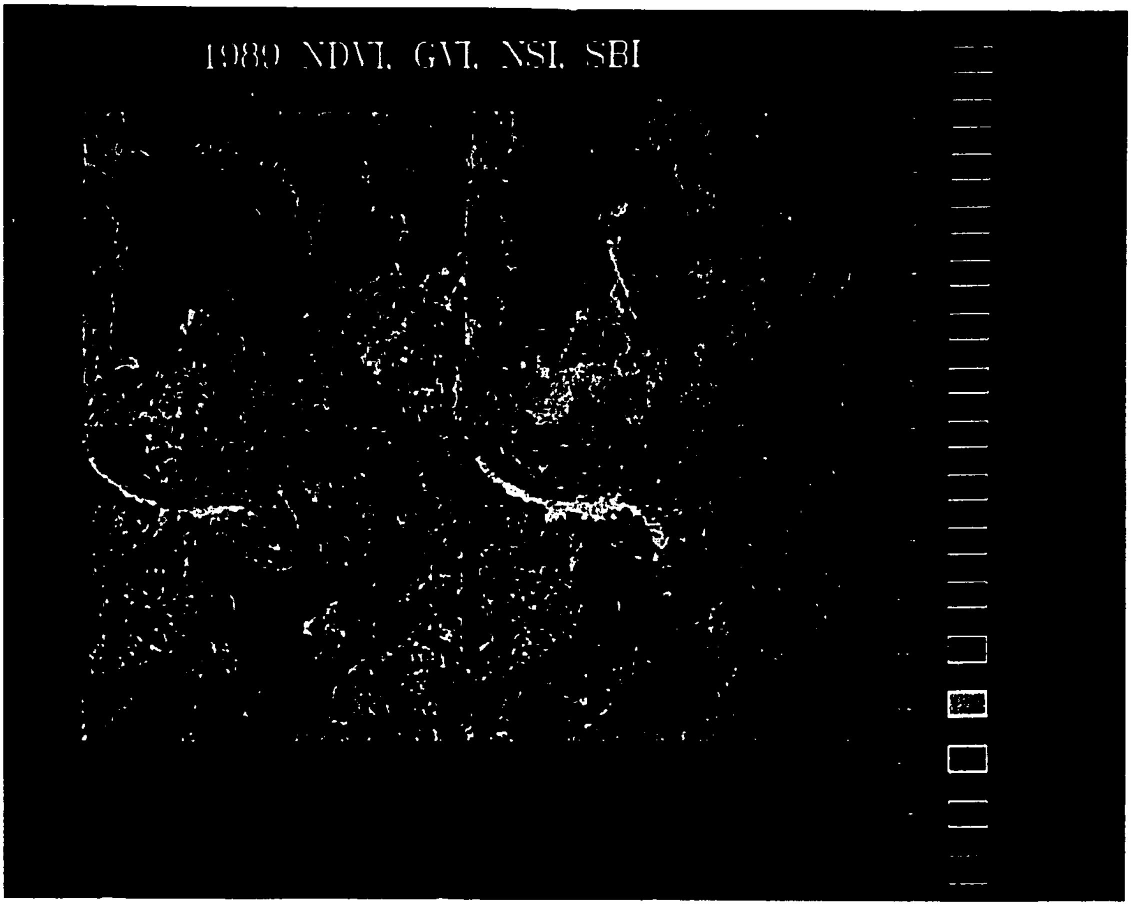

Figure 6. 1989 NDVI, GVI, NSI, SBI Classifications.

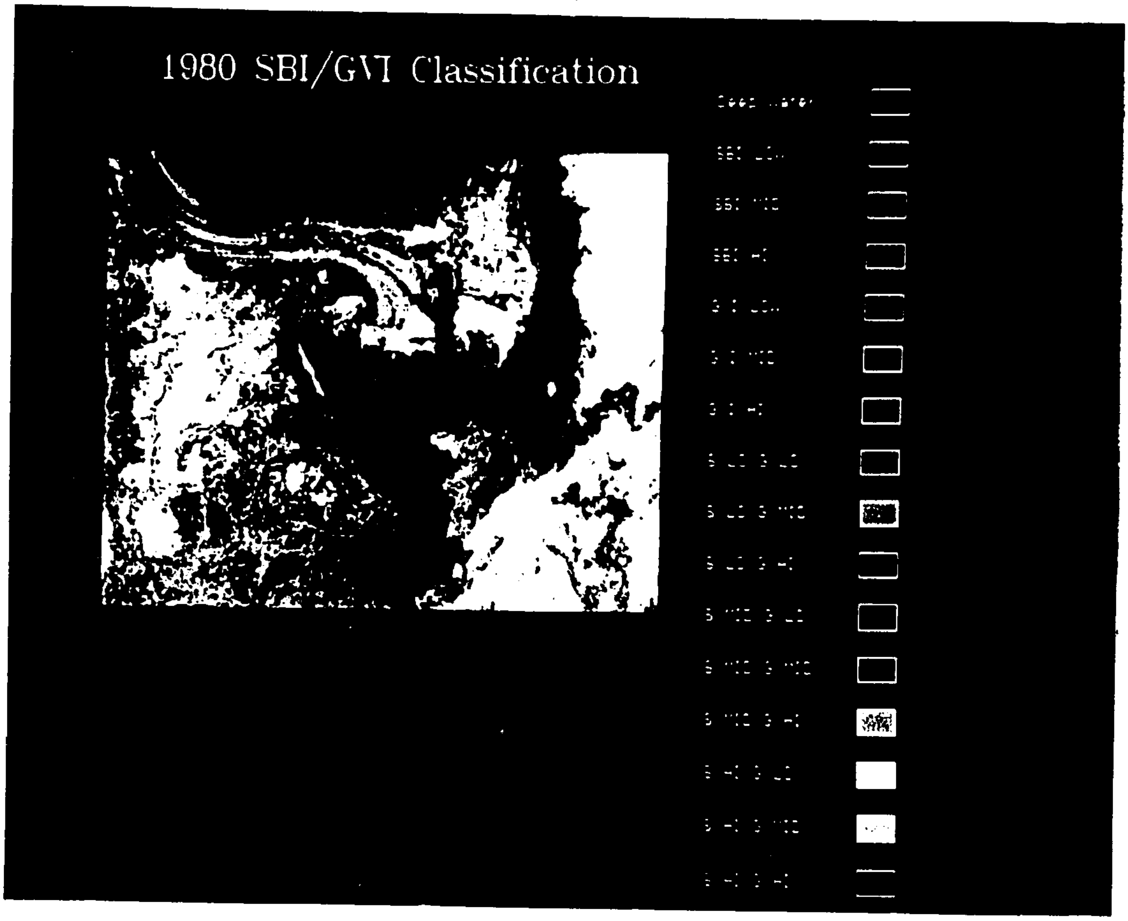

Figure 7. 1980 SBI /GVI Classification.

Figure 8. 1989 SBI/GVI Classification.

Figure 9. 1980 Desertification Classification.

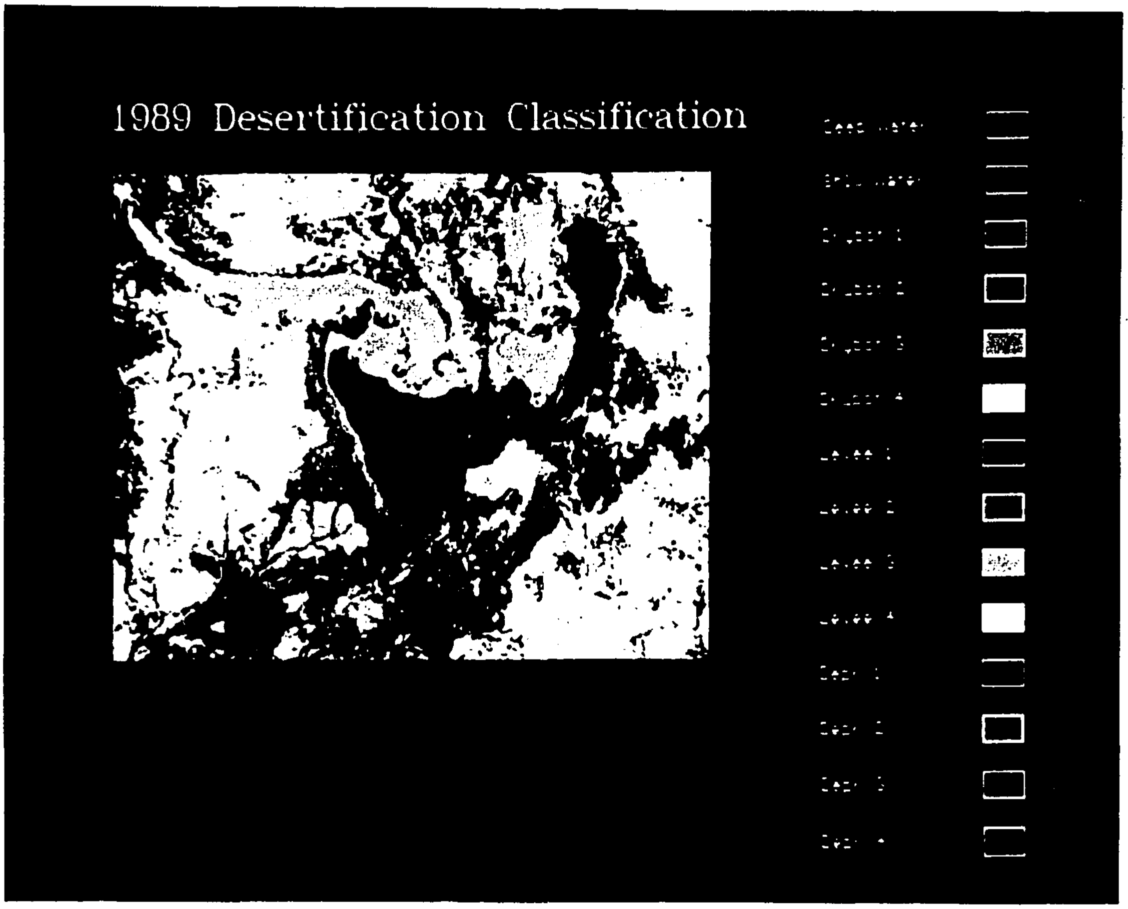

Figure 10. 1989 Desertification Classification.

Appendix C

Methods of Classification

OUTLINE OF PROCEDURES FOR DEVELOPING CLASSIFIED DESERTIFICATION IMAGES†‡¤

I) Procedure for determining dry bottom area classification

1) Digitize vector file: *DRYBOT.vec
2) Create blank image (POLYGON) to transfer rasterized polygon onto
3) Rasterize *DRYBOT.vec
4) Assign POLYGONS using POLY.val[1] to create *DBOT
5) Overlay *DBOT + *FINL to create *DBOT2
6) Assign *DBOT2 values using DRYBOT.val[2] to create *DRYBOT
7) Reclass *DBOT2 values over 16 to 0 (zero) to create *FINL1R
   (this is the original minus the polygon defining dry bottom)

II) Procedure for determining levee area classification

1) Digitize vector file: *LEVEES.vec
2) Create blank image (POLYGON) to transfer rasterized polygons onto
3) Rasterize *LEVEES.vec
4) Assign POLYGONS using POLY.val[1] to create *LEV
5) Overlay *LEV + *FINL1R to create *LEV2
6) Assign *LEV2 values using LEVEE.val[3] to create *LEVEES
7) Reclass *LEV2 values over 16 to 0 (zero) to create *FINL2R
   (this is now the original minus dry bottom and levees polygons)

III) Procedure for determining depressions area classification

1) Assign *FINL2R using DEPR.val[4] to create *DEPR

IV) Procedure for creating the final classified desertification map

1) Assign *LEVEES using 5-8.val[5] to create *LV5-8
2) Assign *DEPR using 9-12.val[6] to create *DP9-12
3) Overlay *DRYBOT + * LV5-8 to create *1
4) Overlay *1 + *DP9-12 to create *CLASSD
5) Assign values 1-4 to 16 in each file to create *DB16, *LEV16, and *DEPR16
6) Overlay *FINL + *DB16 to create *A
7) Overlay *A + *LEV16 to create *B
8) Overlay *B + *DEPR16 to create *C
9) Reclass *C as follows: {16—500=0} to create *UNAREA
10) Assign *UNAREA using A.val[7] to create *UN2
11) Assign *UN2 using B.val[8] to create *UN3
12) Overlay *UN3 + *CLASSD to create *DES1
13) Assign *DES1 using DES.val[9] to create *DESCLS

†Where an * is indicated, either year 80 or 89 would be applied appropriately
‡CAPITAL letters indicate file name
¤Where a superscript ([1]) is indicated, refer to the following values file table

LIST OF VALUES FILES

POLY.val[1]
1 = 20

DRYBOT.val[2]
1-2=0
25=1
26-30=0
31=2
32=0
33=3
34=4
35=0

LEVEE.val[3]
1-30=0
31=1
32=2
33=3
34=4
35=0

DEPR.val[4]
6=0
8=0
9=1
10=0
11=3
12=2
13-14=0
15=4

5-8.val[5]
1=5
2=6
3=7
4=8

9-12.val6
1=9
2=10
3=11
4=12

A.val7
4=13
5=14
6= 7
8=13
9= 9
12=10
13=7
14=8
15=12

B.val8
11=6

DES.val9
1=2
2=3
3=4
4=5
5-6
6=7
7=8
8=9
9=10
10=11
11=0
12=13
13=1
14=2

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