INVESTIGATION OF COMPUTATIONAL PROBLEM AREA DETECTION ON EARTHEN SPILLWAYS ACROSS VARYING IMAGE RESOLUTIONS

By

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INVESTIGATION OF COMPUTATIONAL PROBLEM AREA

DETECTION ON EARTHEN SPILLWAYS ACROSS

VARYING IMAGE RESOLUTIONS

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CHAPTER 1

INTRODUCTION

The state of Oklahoma regulates 4438 flood control reservoirs [1]. The stored water in these structures is most commonly held back by earthen dams. Major rainfall events can fill these reservoirs to the point where the water must be released through vegetated earthen auxiliary spillways. In these events, soil erosion by water can damage or destroy spillways causing the water stored in the structure to be released rapidly which can cause serious flooding downstream of the reservoir. For the majority of these dams, vegetation is used to protect the embankment and auxiliary spillway soil from erosion. Vegetation in poor condition will not provide adequate protection from soil erosion; therefore it is necessary to inspect the condition of these structures to ensure the safety of the people and property downstream of these reservoirs. Currently, inspections are performed manually by inspectors visiting a structure, and the funding available for inspections restricts the frequency of these inspections. Using remotely sensed images could allow for more frequent inspections by reducing the cost of each inspection if vegetation problems could be detected using available imagery. The cost reduction for these inspections could vary significantly depending on what type of remote imagery is used.

In general, it costs more to purchase high resolution imagery than it does to purchase lower resolution imagery. With this in mind, the most efficient use of money for automatic inspections would be to use the lowest resolution imagery that still allows for adequate detection of problem areas.

This work investigates the possibility of automatic spillway inspection using standard computer vision techniques to analyze spillway images. Four segmentation algorithms were used to segment images of ten selected spillways. Varying resolutions were looked at to investigate what resolution might be needed in order to identify vegetal problem areas. Each of the ten spillway images were resized to 7 levels of resolution and each segmentation algorithm was applied to the entire set of images. The results of these segmentations are discussed in terms of a visual analysis and a set of metrics that relates the pixel-wise percent of problem areas segmented for each spillway/ algorithm/ resolution combination.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Vegetated Spillways Background Information

The majority of the 4638 state-regulated flood control structures were built over thirty years ago and many are nearing the end of their intended life cycle, and it is because of this that there is a definite need to improve our evaluation of these structures [1]. One of the issues and methods of extending the life of a structure is proper maintenance, including vegetation.

Figure 2.1 below is an example of a spillway flowing. You can see a gully near the end of the spillway. A gully like this can erode upstream into the reservoir and cause the draining of the entire reservoir.

Figure 2.1 Vegetated spillway being eroded. *Photo courtesy USDA-ARS HERU*

Many factors are considered when determining the quality of vegetation and protection it will provide. Among these factors are the health, height, density, and type of vegetation[22].

Any section of vegetation that is of low quality is a problem for the spillway. In order to function properly the vegetal cover must be uniform and in good condition. Areas of vegetation that are considered of low quality are described as *discontinuities* in spillway literature, but for clarity are referred to as *problem areas* in this work. Problem areas may be areas of unhealthy vegetation, no vegetation, or unwanted vegetation and are classified into two categories: major and minor. A major problem area is one that has dimension parallel to flow that is greater than the height of the vegetation. Minor problem areas are recognizable problems that are not large enough to be classified as major problem areas [22][23][24][25][28]. Figure 2.2 below illustrates one type of problem area; a small mesquite tree that has caused erosion in the immediate area.

Figure 2.2 Example of a major problem area. *Photo courtesy USDA-ARS HERU*

2.2 Segmentation Algorithms

Segmentation is the process of partitioning an image into disjointed and homogeneous regions [9]. Segmenting an image divides the image into smaller parts that can then be classified as to what type of area each part belongs to. There are numerous approaches and algorithms for segmentation. Two often cited surveys of color segmentation, [12] and [18] ,divide all segmentation algorithms into similar categories. These categories are discussed in the sections that follow.

2.2.1 Feature Space Based Segmentation

Segmentation algorithms in this category use features such as color and texture to group pixels into homogeneous segments within an image. One prevalent method of feature space based segmentation is known as clustering. The process of clustering consists of determining the regions $S_1, \ldots, S_K$ such that every x_m, $m = 1, \ldots, M$, belongs to one of these regions and no x_m belongs to two regions at the same time[12]. Clustering plays an important role as a low-level step in other, more complex segmentation algorithms. The idea of grouping pixels into segments based on their color or texture features is fundamental to a good segmentation, but often algorithms focusing solely on these feature spaces produce over-segmented results. Incorporating domain characteristics, as discussed in the next section, often reduces the problem of over-segmentation.

2.2.2 Image Domain Based Segmentation

Image domain based segmentation algorithms incorporate spatial characteristics of image regions in order to produce areas that are homogenous as well as spatially compact [12]. By incorporating spatial characteristics, these algorithms are less likely to produce over-segmented results. [18] further divides image domain based segmentations into two separate categories: area based and edge based.

2.2.3 Physics Based Segmentation

As described in [12], physics based techniques seek to analyze how light interacts with colored materials and to introduce models of this physical interaction into the segmentation process. Many physics based algorithms rely on work done by Shafer in [16] wherein the *dichromatic model of reflectance* is proposed. This model of reflection attempts to define the interaction between a light source and homogenous dielectric (or uniform-colored, non-metal) surfaces [12].

2.3 Selected Segmentation Algorithms

2.3.1 EDISON

EDISON or "Edge Detection and Image SegmentatiON" as it is described by Christoudias et al in [3] implements a version of the mean shift algorithm, which is a feature space based segmentation algorithm. EDISON was chosen because mean shift segmentation is widely used in computer vision and initial trials on spillway images using the EDISON implementation seemed to produce promising results.

2.3.2 GPAC

The Graph Partitioning Active Contours (GPAC) segmentation method is a variant of the Active Contour Modeling (ACM) method described in [17] in which all adjacent pixel pairs in an image are represented as edges of a directed graph. This approach attempts to minimize the cost of graph cuts, or segmentation curves, based on a cost function that measures (dis)similarities between pairs of pixels [19]. GPAC is initiated with a set of curves that are generated based on input parameters x, y, and w. These parameters define the width, height and center, respectively, of a set of initial curves. After initialization, curves are evolved iteratively in the normal direction based on the evaluation of a cost function. Segmentation results can differ with different initial curve sets, which make parameter selection important.

2.3.3 JSEG

The JSEG method of segmentation incorporates two distinct stages. The first stage is a color quantization that divides colors found in the image into classes based on the spectral distribution. These classes are created in the color feature space without regard to the spatial distribution of the colors in the image [5]. Pixels in the image are then labeled based on the color class map created in the first stage. In the second stage a region-growing method is applied to the labeled pixels wherein spatial characteristics of the segmented regions are analyzed to determine which regions should be merged This method of segmentation was chosen because the natural images we are working with seem to have distinct spectral ranges for the natural features to be segmented, which should work well with method employed in the first stage of this algorithm

2.3.4 Pyramid

Pyramid segmentation is an early and well-recognized algorithm with many variations. In general, the algorithm generates a pyramid structure of decreasing resolution levels (or copies) of an image. This is accomplished by sampling pixels from lower levels of the pyramid to create the next level above. In the algorithm used for this work, pixels for a given level are linked to a parent pixel in the level above, based on the error threshold discussed below. Once the pyramid has been built to the maximum level, pixel values are then passed down from parent to children until all pixel values have been propagated to the lowest level of the pyramid[14]. The result of this propagation to the lowest level is the segmentation of the original image. The implementation used for this thesis work comes from the OpenCV Image Processing Library[11]. The threshold parameters for linking adjacent levels and clustering pixels within a level are described in the OpenCV documentation [11] for RGB images as follows:

The links between any pixel on one level and its candidate parent pixel on the adjacent level are established if the color distance between adjacent pixels is less than the link threshold. After the connected components are defined, they are joined into several clusters. Any two segments belong to the same cluster, if color the distance between the two segments is less than the cluster threshold.

CHAPTER 3

METHODOLOGY

In order to investigate the ability to automatically detect problem areas, high resolution images of vegetated spillways were required. After a brief survey of the types of available commercial imagery and their associated costs, it was determined that aerial imagery of locally accessible spillways would be the best option. The images acquired were taken by a camera described in Appendix D. In the following sections the process of data gathering/processing, segmentation, and results calculation are described. Figure 3.1 on the next page illustrates the major workflow components of this thesis work.

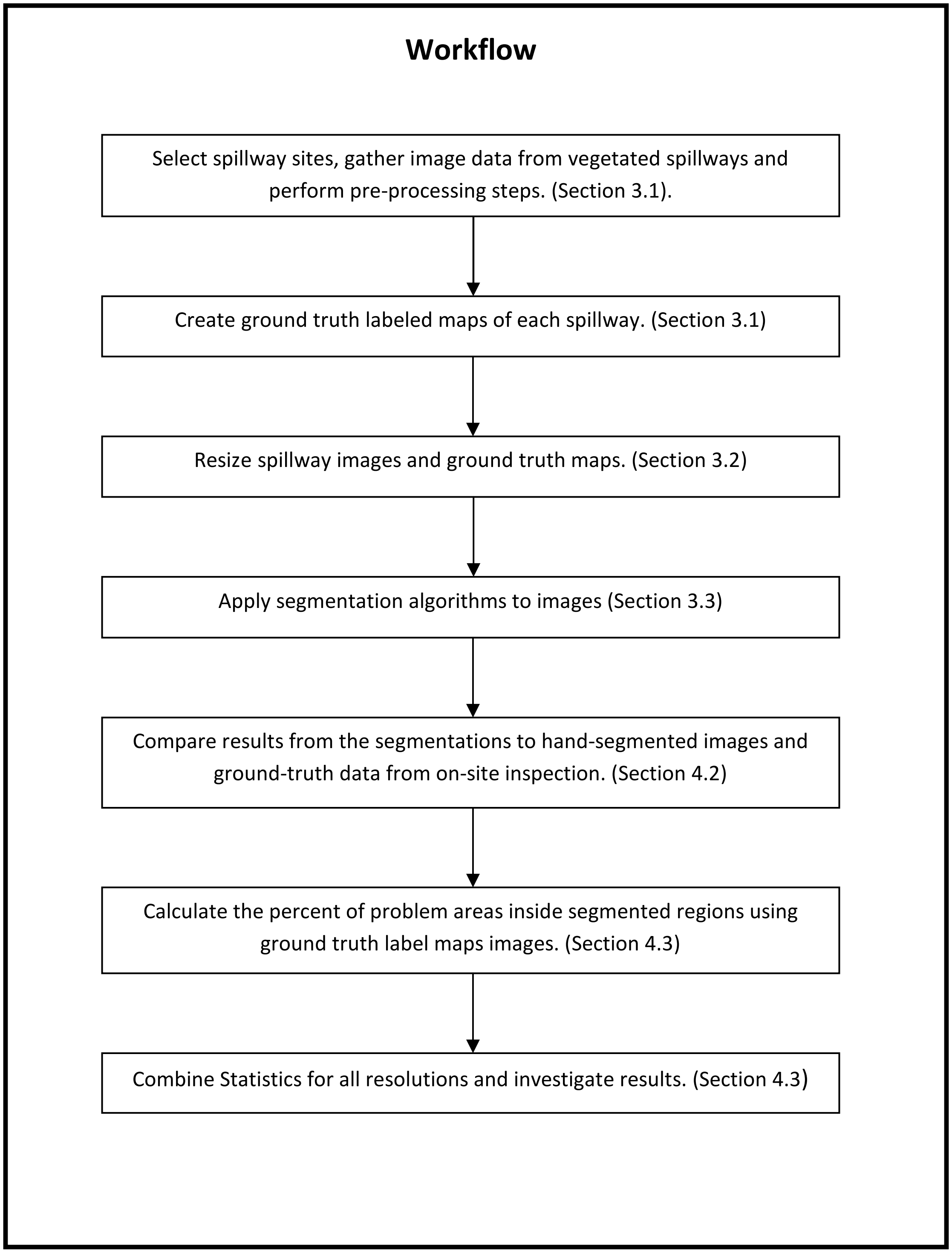


Figure 3.1 Flow Chart of Thesis Work.

3.1 Site Selection and Ground Truth Collection

The sites to be photographed were chosen based on their accessibility, spillway condition and location. Using Google Earth® and GPS coordinates from the National Inventory of Dams Database [1], nine locations were chosen in Payne and surrounding counties. Of these, three were chosen that appeared to have a maintenance code of 1, 3 were chosen with a maintenance code of 2, and 3 were chosen with a maintenance code of 3. All of the sites chosen were state regulated flood control structures. Access to these sites was facilitated by the NRCS State Office as well as District Conservationists for each of the counties that contained a chosen site. Three in-person visits to each site were made. Two of the visits were prior to the aerial images being taken, and the final visit was made just after the aerial images were made. In addition to the nine spillway sites, one site at the ARS Hydraulic Lab was also photographed. This site contained manually dug, bare soil problem areas of varying sizes and shapes.

On the initial visit, each site was evaluated as to whether or not the site would be useful for this investigation. All of the sites that had been chosen were determined to be acceptable. Each location was marked on the initial visit by placing 3ft x 3ft black targets 100ft apart. The purpose of the targets was to provide accurate ground truth locations for processing in later steps. Two experts on vegetal maintenance and spillway erosion, Greg Hanson and Darrel Temple, accompanied on a second visit to the sites [20]. On this visit, each site was photographed, reviewed, and assigned an overall maintenance code as described in Appendices B and C. Maintenance codes reported in this work were assigned by Darrel and Greg based on their inspection of the each spillway. Also, each problem area was discussed and classified as major or minor. After the photos were taken, a final visit was made to each site to gather the targets and to measure off more ground control points for those sites where targets were destroyed or missing.

For each site a groundtruth map was created. Using site notes and ground photos from the site visits, problem areas were marked manually on each initial spillway image using an image editing program. Problem areas consisting of bare soil were marked in black and problem areas consisting of trees or undesirable plants were marked in white. The area remaining unmarked was colored blue to represent the regions not containing problem areas. Statistics for each of the spillways were recorded and can be found in Appendix C. Figure 3.2 below illustrates a completed ground truth map and the image that the map was created from.

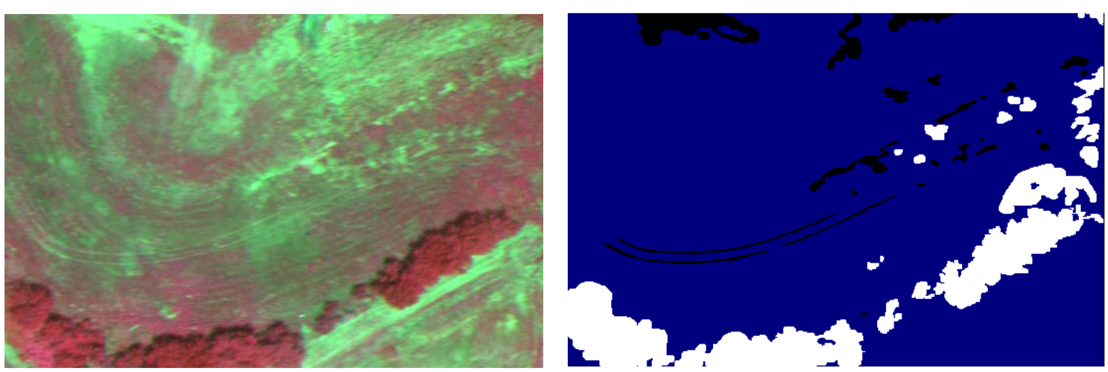


Figure 3.2 Spillway aerial image(left) and its corresponding groundtruth map(right).

Areas of bare soil were distinguished in the groundtruth maps from trees and undesirable plants because of the differences in shape and color between the two types of areas. Throughout the rest of this work, problem areas of bare soil are referred to as Type 1 problem areas. Similarly, problem areas consisting of trees or undesirable plants are referred to as Type 2 problem areas. Segmentation results in Chapter 4 are presented separately, in some cases, for these two types in order to compare how well the algorithms are performing on each type. Figure 3.3 below shows the difference between the two types of problem areas.

Figure 3.3 Example of a Type 1 problem area consisting of a bare soil path (left). Example of a Type 2 problem area consisting of a small tree (right).

3.2 Image Preparation

The initial resolution for each image was calculated by counting the number of pixels between groundtruth targets located on the images. Using the known distance between the ground control points and the number of pixels representing this distance in the image, an estimated resolution in cm/pixel was calculated for every spillway image. Images were left as photographed for the initial resolution, and due to the varying altitude at which the photos were taken, the resolution in these images ranges between 17cm and 20cm. To create the next resolution level, all images were re-sampled to 1 foot resolution. In addition to the initial resolution, seven lower levels of resolution were created and segmented for each spillway. The resolution levels were chosen to mimic resolutions of current high resolution commercial imaging satellites and are as follows: 30.48cm(1ft), 50cm, 60.96cm(2 ft), 70cm, 100cm, 150cm, and 184cm.

In order to speed up the processing of the algorithms each image was cropped to the spillway region. Two of the photos (Bear 13 and Stillwater 26) had to be rotated before cropping in order to get the image file-size down to the level needed to be able to process the algorithms in memory.

3.3 Selection and Application of Segmentation Algorithms

Four implementations of segmentation algorithms were chosen to be applied to the set of varying resolution spillway images. For the purposes of automatic detection, the implementation of a segmentation algorithm must be non-interactive. Any parameters need to be well-established so that runs over many spillway images are consistent. An effective algorithm will require no tuning once the parameters are established.

As described in section 2.3, the algorithms that were chosen are: EDISON, GPAC, JSEG, and Pyramid Segmentation. Each of the selected algorithm implementations required a set of input parameters. A reasonable set of parameters for each algorithm was found by visual observation of segmentation results while varying the input parameter sets used. Two spillway images, one with maintenance code 1 and one with maintenance code 3 were tested with each set of trial parameters. This was done with the hope of finding a set of parameters for each algorithm that worked well across the spectrum of spillway conditions. The resulting parameter sets used for all the segmentations are described in Appendix A.

Once a set of parameters were established, each algorithm was then applied to each spillway image at each resolution, resulting in 320 segmentation attempts. Due to the very small size of some of the lower resolution images, however, not every attempt at segmentation was successful. Pyramid and GPAC were not able to segment many of the smaller images. The results of the successful attempts are detailed in the next chapter. The outputs of the segmentations were stored as images for later processing and visual inspection.

3.4 Result Metrics

In order to get a better understanding of the segmentation results as resolution decreases, three percentages were developed to measure how well groundtruth problem areas are being fit by the segmentations. Figures 3.4 and 3.5 below are examples of the two areas used in the calculating percentages. Area A, as shown in Figure 3.4, is a groundtruth problem area. Area B, as shown in Figure 3.4, is an area of a segment that intersects Area A. The intersection is found by comparing the groundtruth map in Figure 3.4 to the segmentation in Figure 3.5. Areas A and B are used throughout this section to describe the calculation of metric percentages.

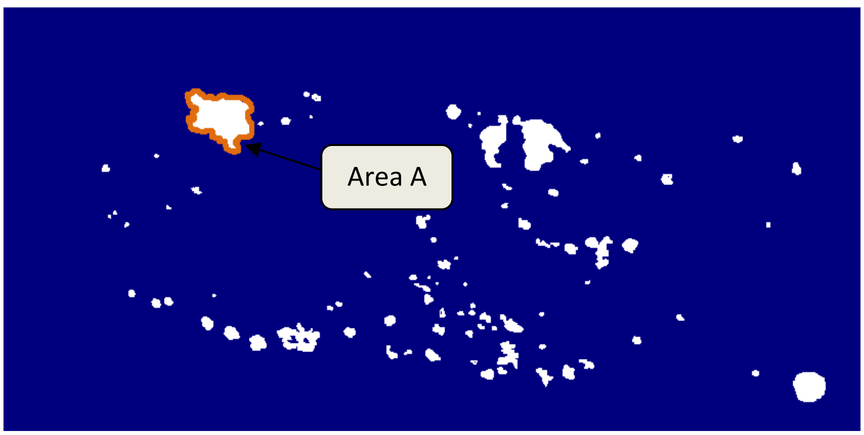


Figure 3.4 Stillwater Creek Site 28 groundtruth map highlighting a groundtruth problem area (Area A).

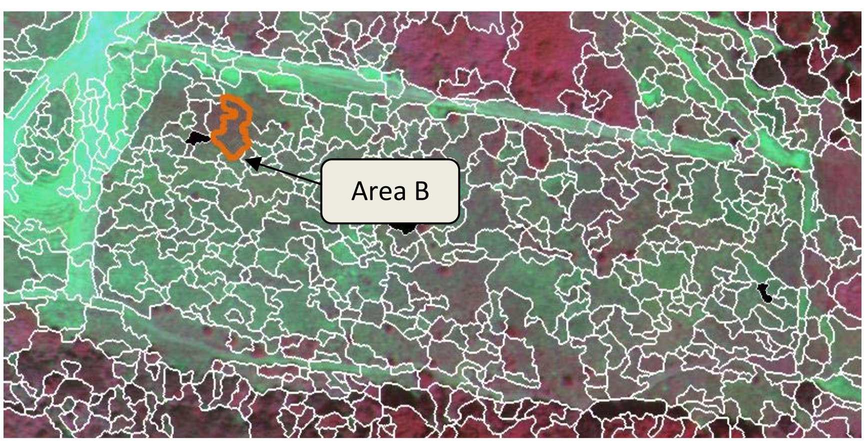


Figure 3.5 Stillwater Creek Site 28 segmentation by JSEG highlighting a segment that intersects Area A from Figure 3.4.

Figure 3.6 below shows an intersection of A and B. The three metrics reported in this work use the cardinality(number of pixels) of the areas A, B, and C for percent calculation.

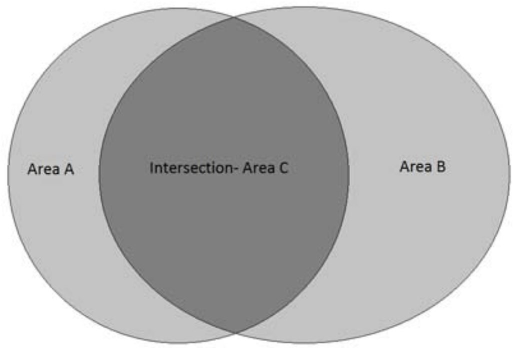


Figure 3.6 Venn diagram of an intersection (Area C) between a groundtruth problem area(Area A) and a segment area (Area B).

Multiple segment areas often intersect a single groundtruth problem area, but only one intersection is considered. Figure 3.7 below illustrates the selection of the *best match segment*. In the figure, Area A is intersected by several areas (B_1, B_2, B_3). Area B_1 has the largest intersection(Area C_1), so in the Figure 3.7, B_1 represents the best match for Area A.

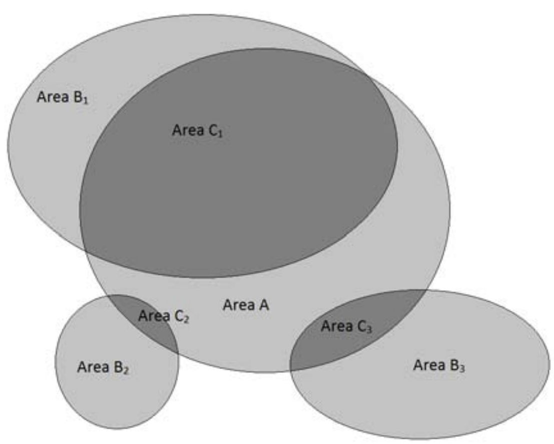


Figure 3.7 Venn Diagram illustrating a best match segment.

3.4.1 Metric 1- Percent In

The first metric calculated is referred to as *Percent In*, and it represents the percentage of a groundtruth problem area that is filled by a best match segment. Using the areas described in Figures 3.4-3.7 it can be calculated as $|C|/|A|$. The *Percent In* metric shows how well a segmentation is covering the groundtruth problem areas. High percentages reported in this metric indicate the algorithm is not under-segmenting the image.

3.4.2 Metric 2- Percent Filled

The second metric calculated is referred to as *Percent Filled*, and it represents the percentage of a best match segment filled by a groundtruth problem area. Using the areas described in Figures 3.4-3.7 it can be calculated as $|C|/|B|$. High percentages reported in this metric indicate the algorithm is not over-segmenting the image.

3.4.3 Metric 3- Best Match Percent Filled

The final percentage calculated demonstrates how well a *best match segment* is filled by groundtruth problem areas. Figure 3.8 on the next page shows a diagram of the groundtruth problem areas(A_1, A_2, A_3, and A_4) that intersect a best match segment(Area B). Using figure 3.8 as an example, this metric is calculated as:

$(|C_1| + |C_2| + |C_3| + |C_4|) / |B|$. A high percentage in this metric is helpful in determining whether or not a segmentation algorithm is merging multiple, small problem areas.

If a high percentage is reported for this metric, but not for *Percent In* and *Percent Filled*, it might be indicate that multiple problem areas near one another are being segmented as one area, which would mean the algorithm is performing better than the other two metrics are indicating.

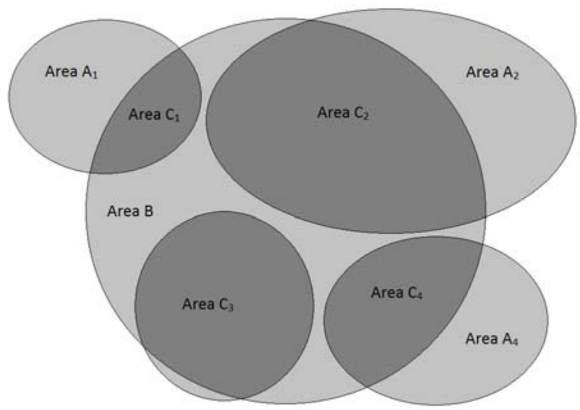


Figure 3.8 Venn diagram illustrating Metric 3- Best Match Percent Filled

CHAPTER 4

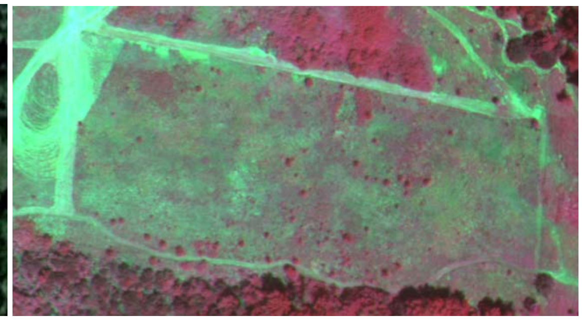
RESULTS

In addition to the metrics discussed in the previous section, the results from each segmentation were analyzed and compared visually to one another. Visual inspection of the segmentations indicates that EDISON is performing well. JSEG and Pyramid both seem to be under-segmenting Type 2 problem areas. At the same time, JSEG also appears to over-segment some areas of uniform vegetation that should make up only one large segment.

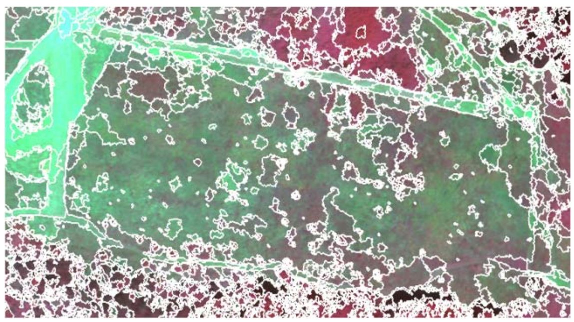
Figure 4.1 on the next page illustrates a natural color image, an aerial image, and results from each of the segmentation algorithms used. The natural color image in figure 4.1 was taken several years prior to the aerial images used for segmentation, so the growth of trees and other problem areas does not match the aerial image. The natural color image is provided as a reference to help understand the content of the filtered color in the aerial images.

Figure 4.1c demonstrates that EDISON segments Type 2 problem areas better than JSEG(4.1e) and Pyramid(4.1f). The small trees in the center of the spillway are fit much better by EDISON than by JSEG or Pyramid. JSEG and Pyramid seem to segment several trees into one larger segment whereas EDISON segments more trees individually.

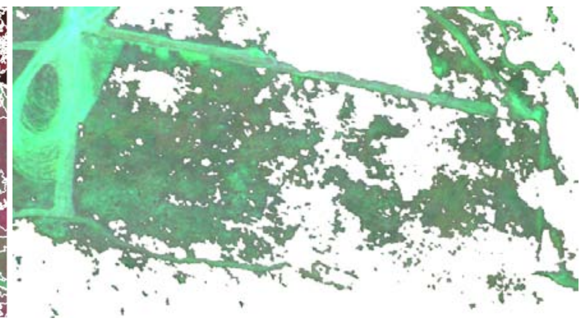
(a)



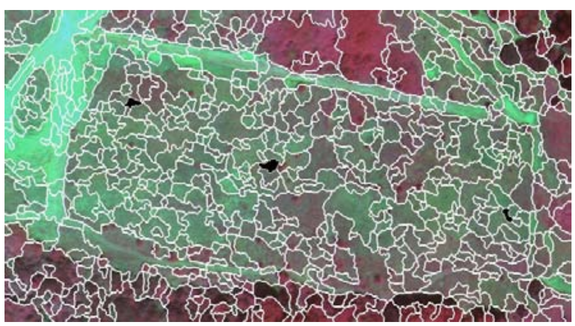
(b)



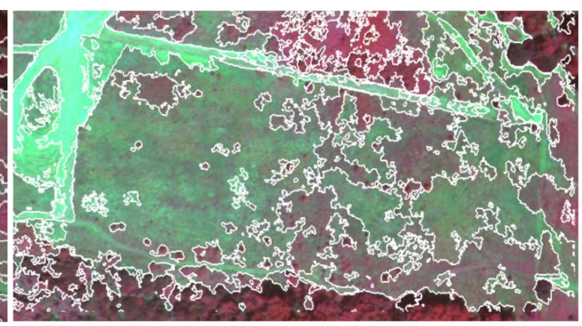
(c)



(d)



(e)



(f)

Figure 4.1 Examples of Segmentations from Stillwater Creek Site 28. (a) A natural color image of the spillway from Google Earth®. (b) The original aerial image. (c) EDISON segmentation. (d) GPAC segmentation (e) JSEG segmentation. (f) Pyramid segmentation

4.1 Charted Results

Figure 4.2 below illustrates *Percent In* metric as described in Section 3.4.1. Many of the statistics for lower resolutions in this chart score very high, but due to high number of problem areas containing only a few pixels at those resolutions, one must be careful not to draw any meaningful conclusion from these results. A good segmentation will produce high percentages for all three metrics. A high percentage reported for *Percent In* without a corresponding high percentage in *Percent Filled* indicates under-segmentation. In contrast, a low percentage reported for *Percent In* with a corresponding high percentage for *Percent Filled* indicates over-segmentation.

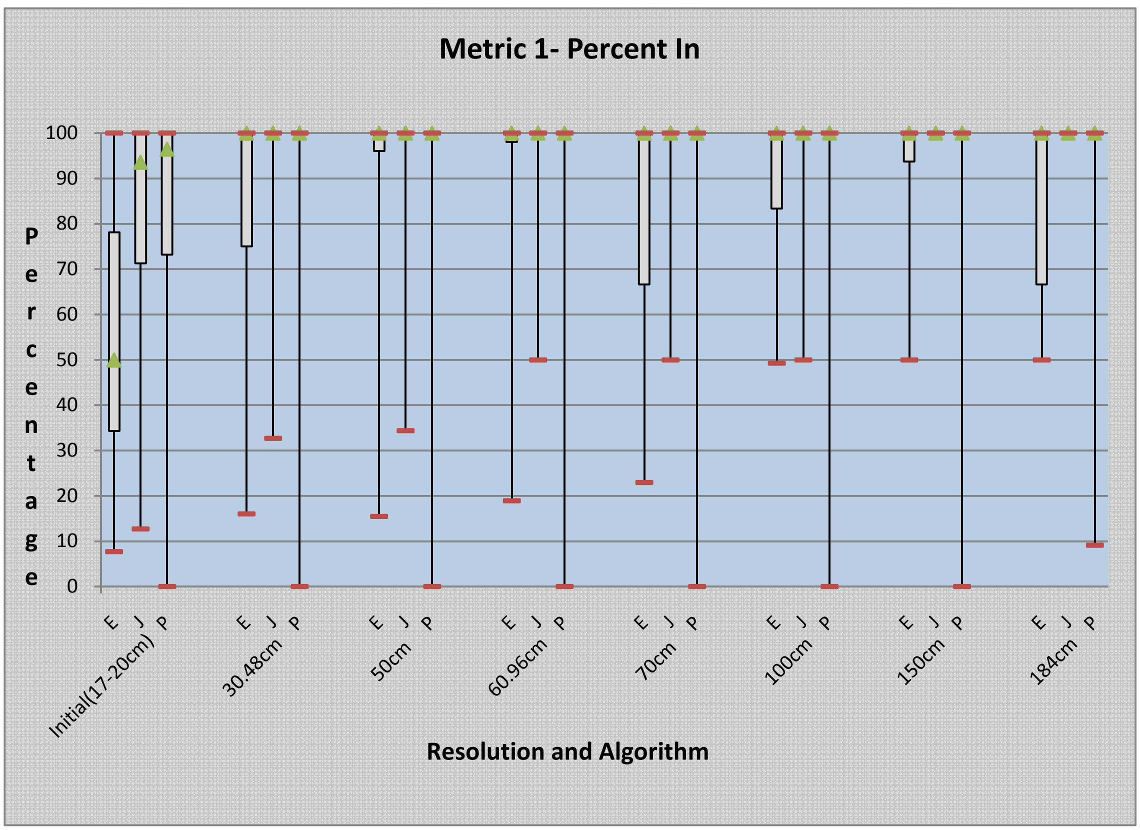


Figure 4.2 Box plot of Metric 1-Percent In. Labels E, J, and P on the X-axis represent results from EDISON, JSEG, and Pyramid, respectively.

Figure 4.3 below illustrates the *Percent Filled* metric for EDISON, JSEG, and Pyramid as described in Section 3.4.2. JSEG and Pyramid algorithms exhibit very poor results based on this metric. This could be caused by the under-segmentation of Type 2 problem areas as mentioned in the beginning of this chapter. Under-segmentation of these regions, which are problem areas, would make the size of the segment large relative to the size of the problem area.

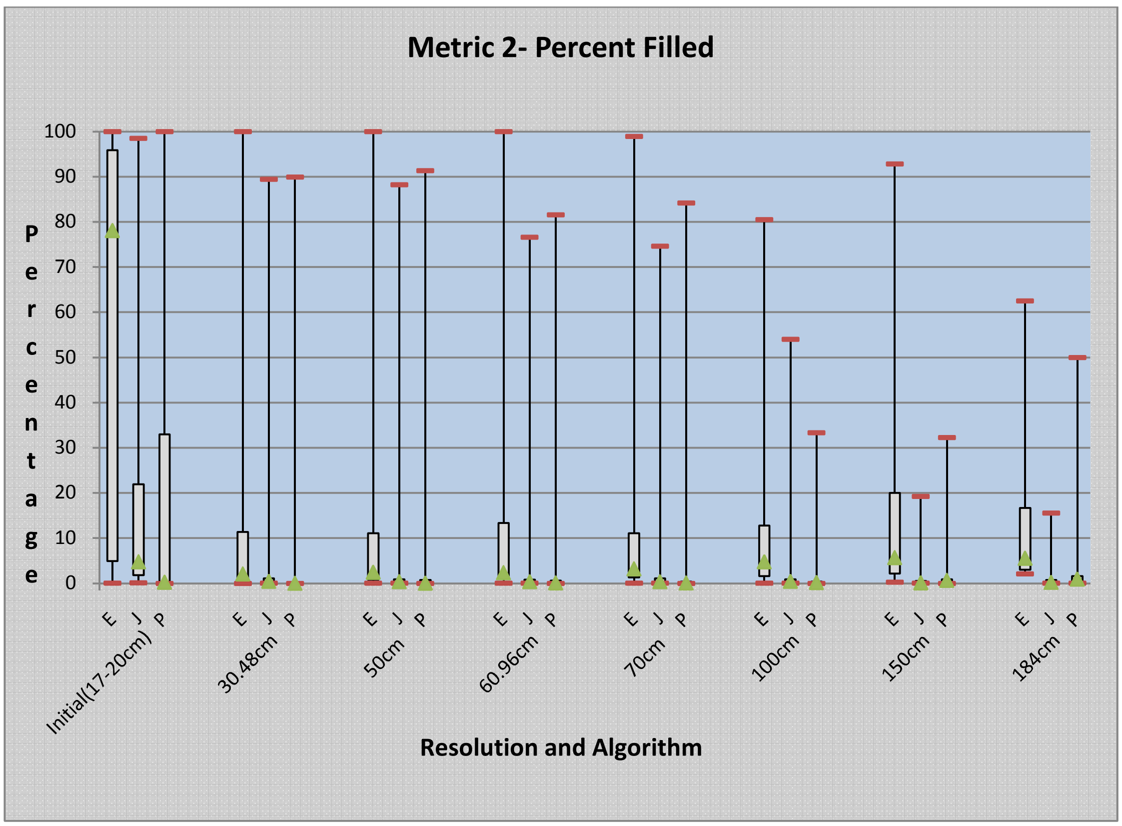


Figure 4.3 Box plot of Metric 2- Percent Filled. Labels E, J, and P on the X-axis represent results from EDISON, JSEG, and Pyramid, respectively.

Figure 4.4 on the next page illustrates the *best match percent filled* metric as described in Section 3.4.3. The most noticeable result from this figure is the performance of the EDISON algorithm compared to the other two algorithms. EDISON outperforms the other algorithms based on this metric. This result, combined with the visual analysis indications seem to show that EDISON is the best of the algorithms used in this work.

Also, slightly noticeable is the decreasing trend for all algorithms as resolution decreases, however, there is no clear point at which results drop off sharply. A gradual decline is observed. As in the previous figure, the JSEG and Pyramid algorithms exhibit lower percentages filled than EDISON which agrees with the visual analysis' suggestion that problem areas are under-segmented in many cases.

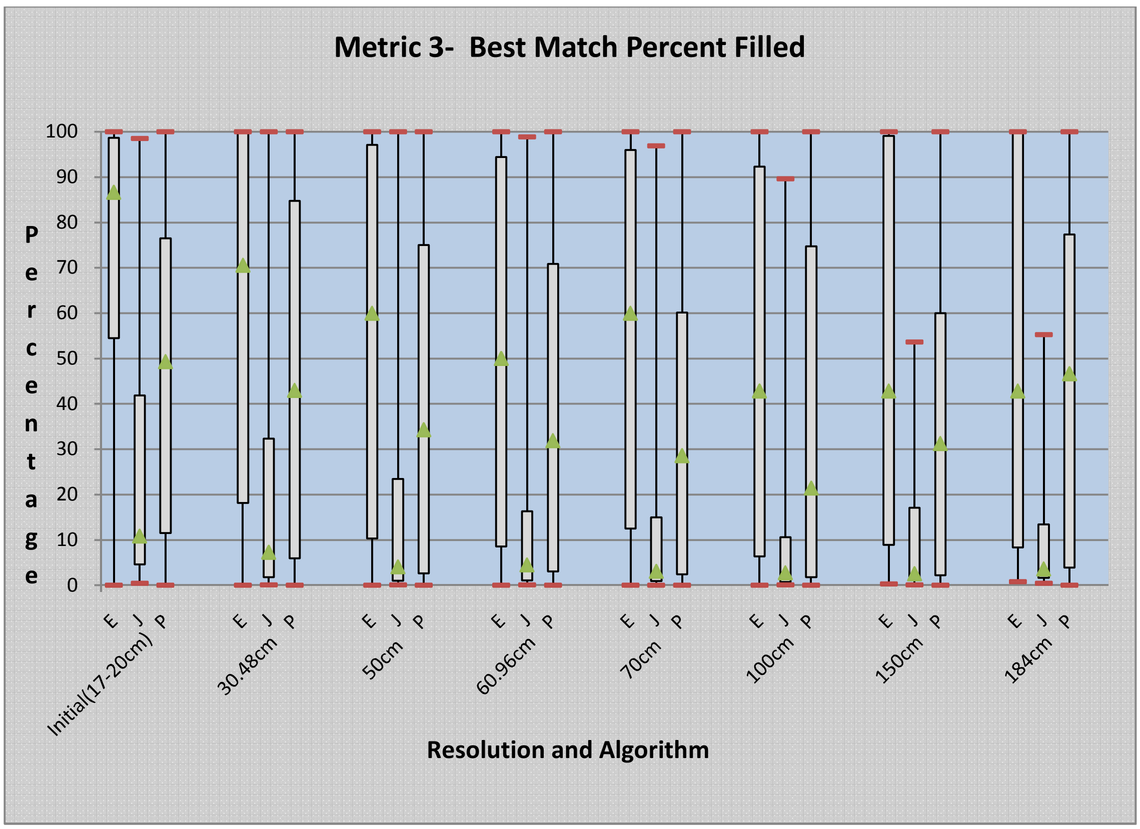


Figure 4.4 Box plot of Metric 3- Best Match Percent Filled. Labels E, J, and P on the X-axis represent results from EDISON, JSEG, and Pyramid, respectively.

4.2 GPAC Results

The GPAC implementation used in these experiments produces two regions, a foreground and background. In the spillway images, three dominant types of areas exist: woody plants, vegetation, and soil. Depending on the content of the image, the GPAC implementation segments woody plants or bare soil in the foreground and vegetation in the background. While this might be useful on spillways containing only Type 1 problem areas or only Type 2 problem areas, it would not be effective for spillways containing both. Another issue with this particular implementation of GPAC is the sensitivity to input parameters. There may be a method for automatically calculating a parameter set based on predetermined characteristics for each image that would produce reasonable results, but that was not pursued. The GPAC implementation used in this work might be valuable for segmenting the spillway region from the non-spillway regions, but for the purpose of detecting vegetal problem areas, it is not effective. Figure 4.5 below illustrates the foreground/background segmentation by GPAC. The area in white is one segment, and the remaining area represents the other segment.

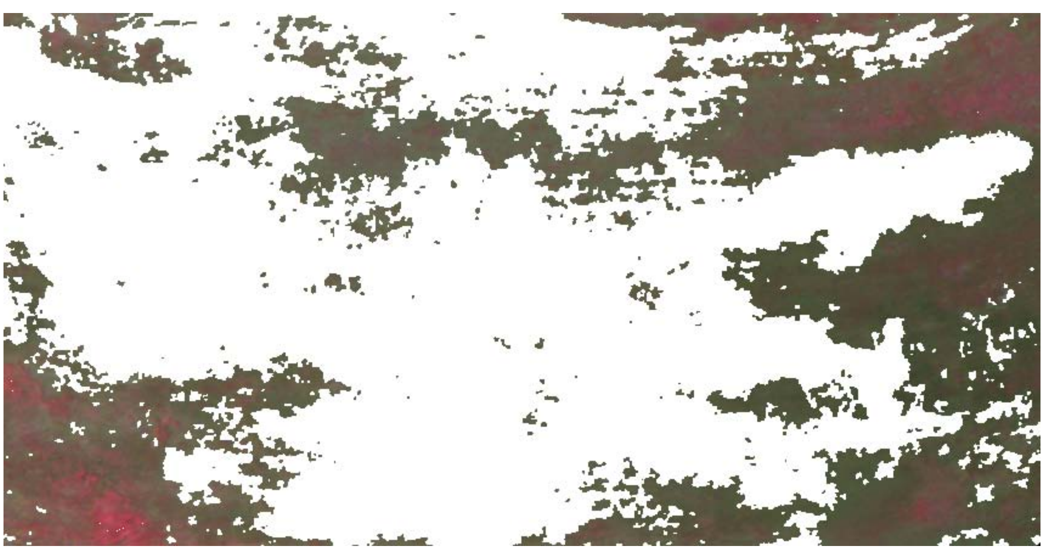


Figure 4.5 GPAC Segmentation of Stillwater Creek Site 26

4.3 JSEG Results

In comparing Figure 4.6 and 4.7 below, the degradation of segmentation with decreasing resolution is illustrated. Comparing the segment sizes in Figures 4.6 and 4.7, it can be easily seen how the *Percent In* metric is reported at such a high rate for the JSEG algorithm. Groundtruth problem areas are relatively small compared to the segments produced by JSEG at lower resolutions.

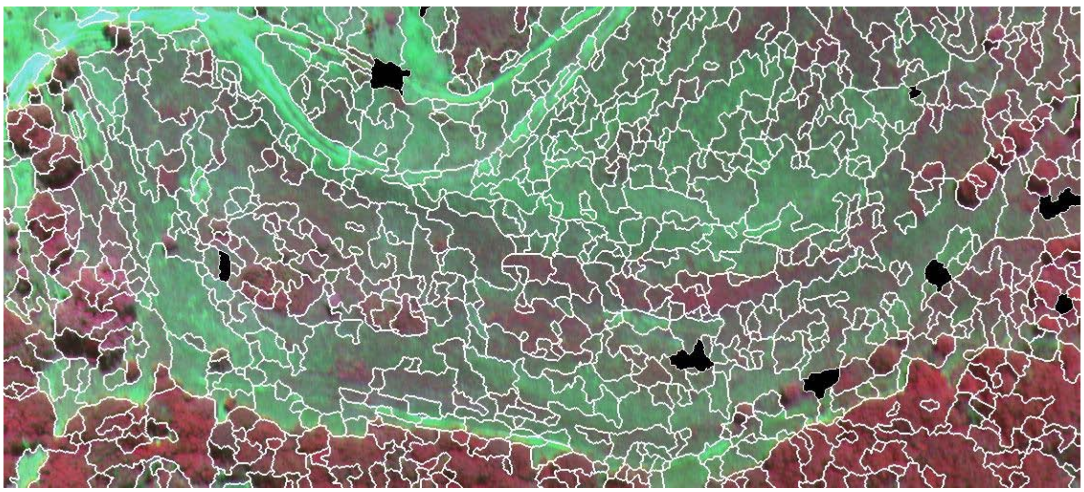


Figure 4.6. JSEG segmentation of Salt Camp Creek Site 6 at initial resolution

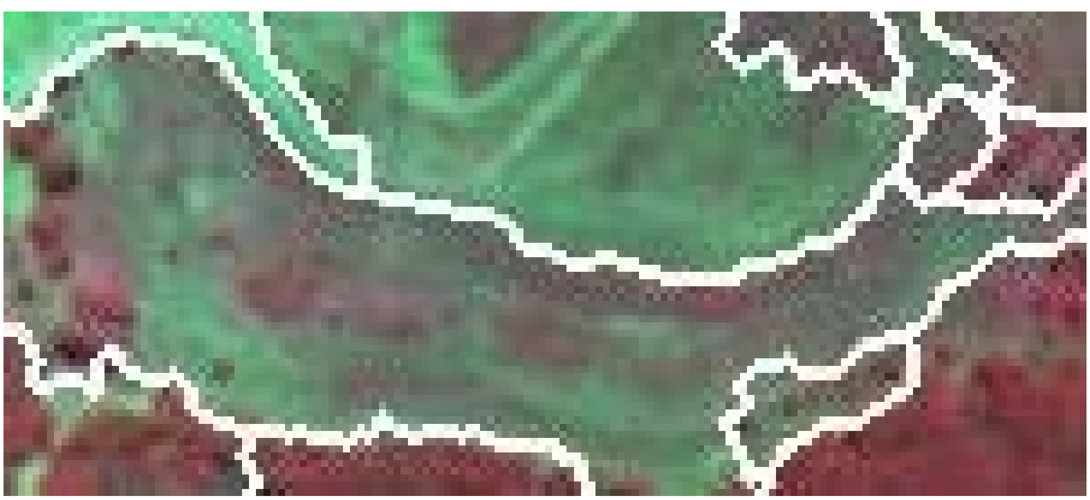


Figure 4.7. JSEG segmentation of Salt Camp Creek Site 6 at 150cm resolution. This image has been enlarged for viewing purposes.

Figure 4.8 below demonstrates again that JSEG segments become relatively large as resolution decreases, and that under-segmentation is a problem not only for Type 2 problem areas, but also for Type 1 problem areas as resolution decreases.

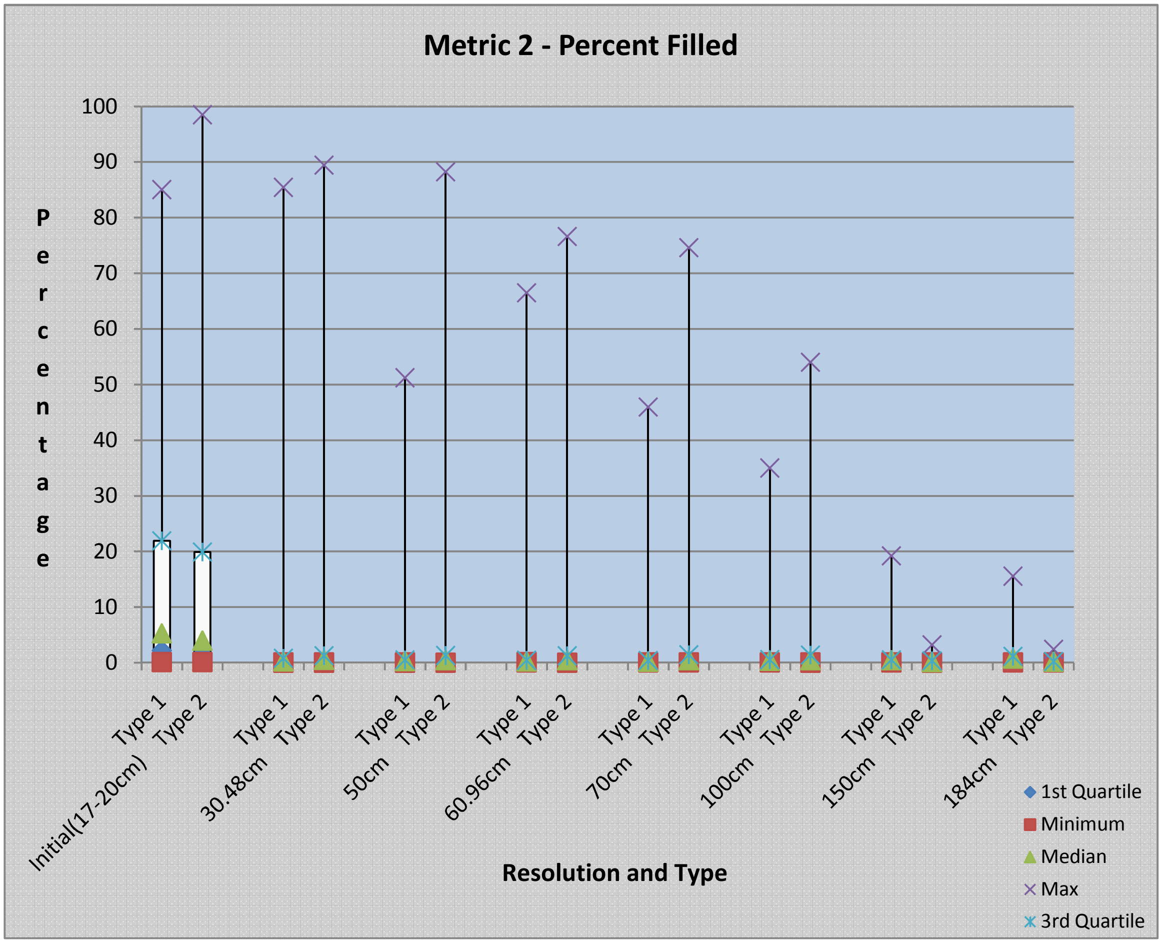


Figure 4.8 Metric 2- Percent Filled for the JSEG algorithm, separated by problem area type.

4.4 Pyramid Results

Based on the metrics in this work, Pyramid segmentation algorithm does a better job than segmenting problem areas than JSEG. The Pyramid algorithm produces reasonable results for Type 2 problem areas across the resolution range. Figure 4.9 below appears to show that the Pyramid algorithm is under-segmenting both types of problem areas. Figure 4.10 on the next page illustrates that the Pyramid algorithm may be merging multiple Type 2 problem areas into one segment, rather than generating a large segment with only a few, relatively small, intersecting problem areas.

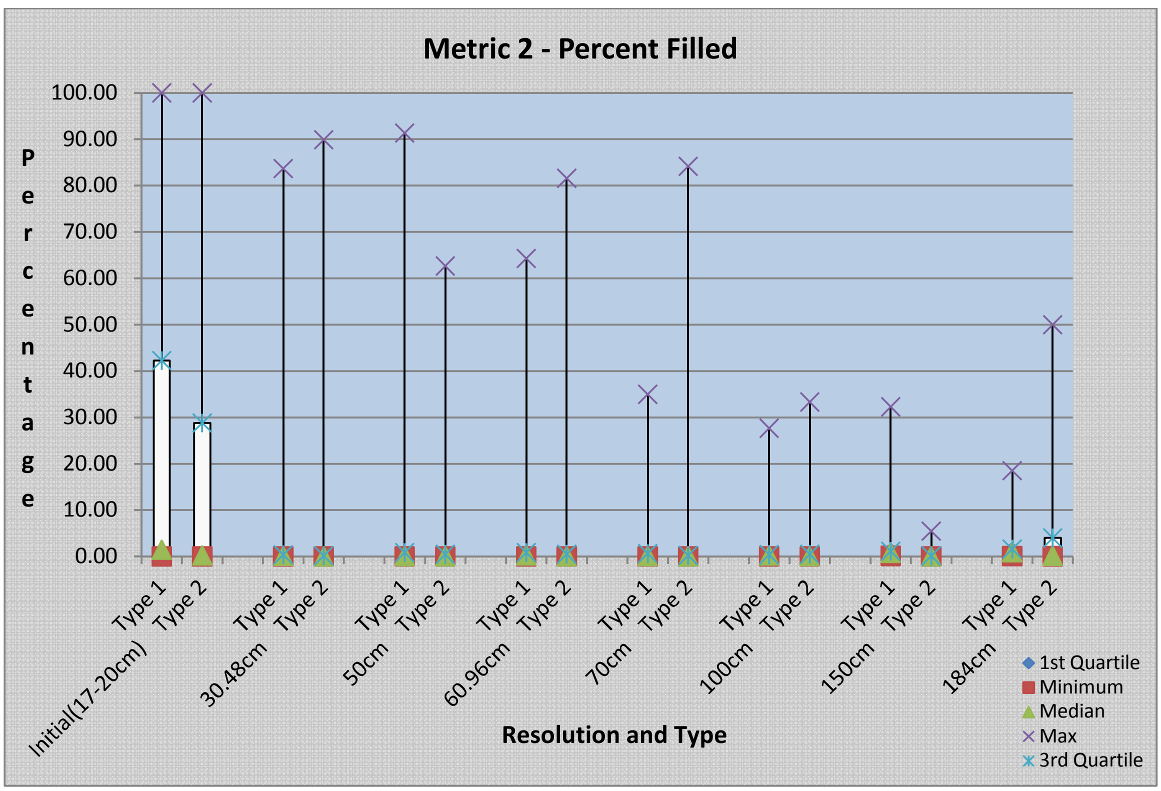


Figure 4.9 Metric 2- Percent Filled for the Pyramid algorithm, separated by problem area type.

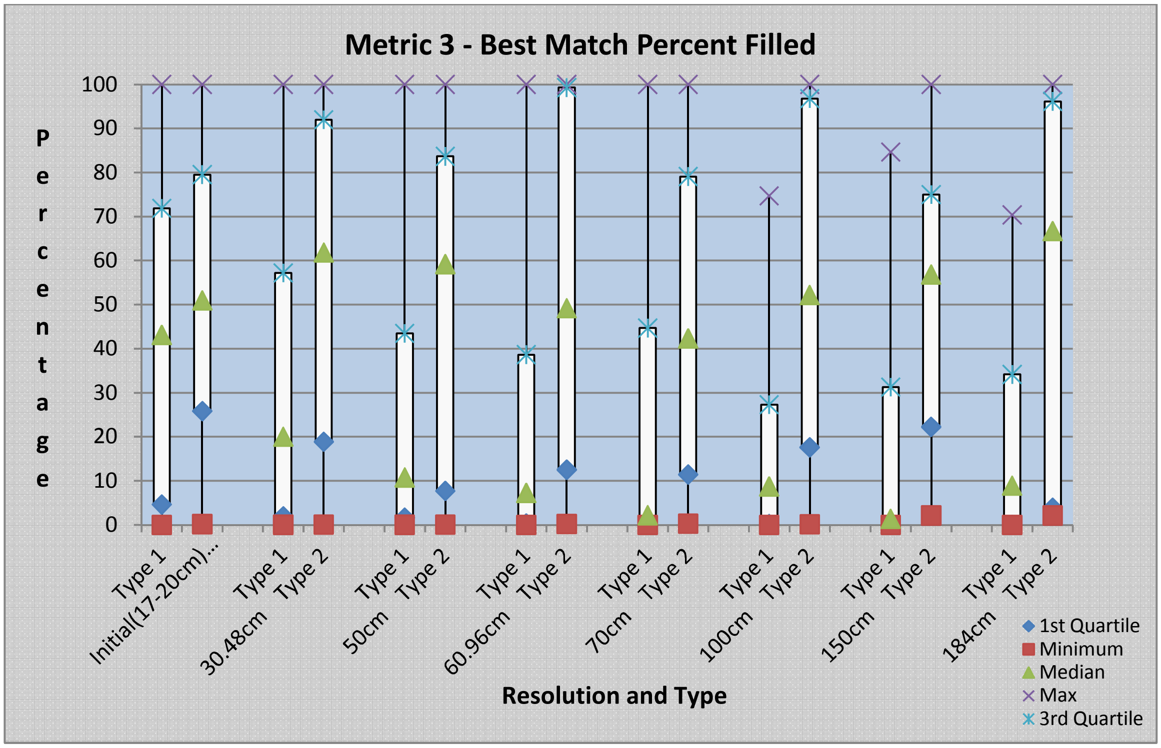


Figure 4.10 Metric 2- Best Match Percent Filled for the Pyramid algorithm, separated by problem area type.

In figure 4.11 on the next page, the Pyramid Algorithm tightly segments most of the Type 1 (bright green segments) problem areas. Some Type 2 problem areas (reddish-pink segments), however, are segmented tightly while others are grouped into one larger segment. These larger segments explain how Pyramid performs better according *Best Match Percent Filled* than according to *Percent Filled*.

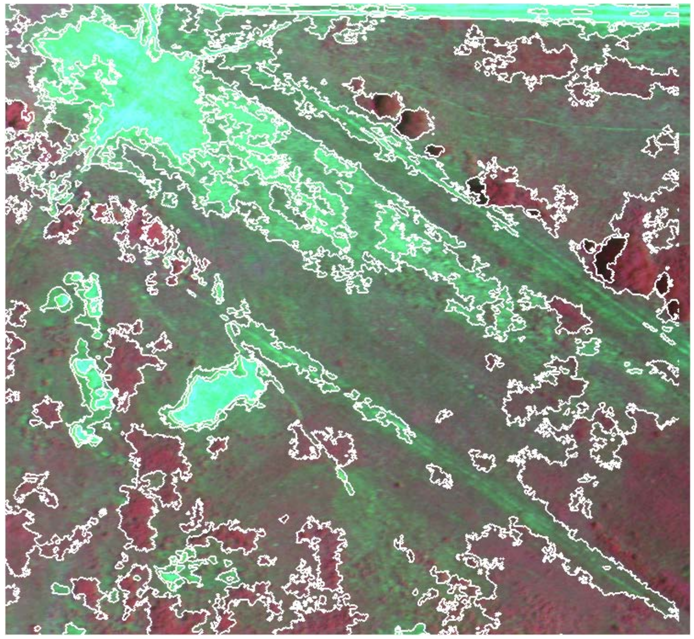


Figure 4.11 Pyramid Segmentation of Little Deep Fork Site 38 at initial resolution

4.5 EDISON Results

Based on an analysis all of the metrics used in this work, EDISON produces the best segmentation results for detection of problems areas of both types. Figure 4.12 on the next page details the *Percent Filled* results for EDISON. The most glaring observation from this figure is the sharp decline in the percentage after the initial resolution. The sharp decline indicates that EDISON might produce significantly larger segments in the second resolution than in the first.

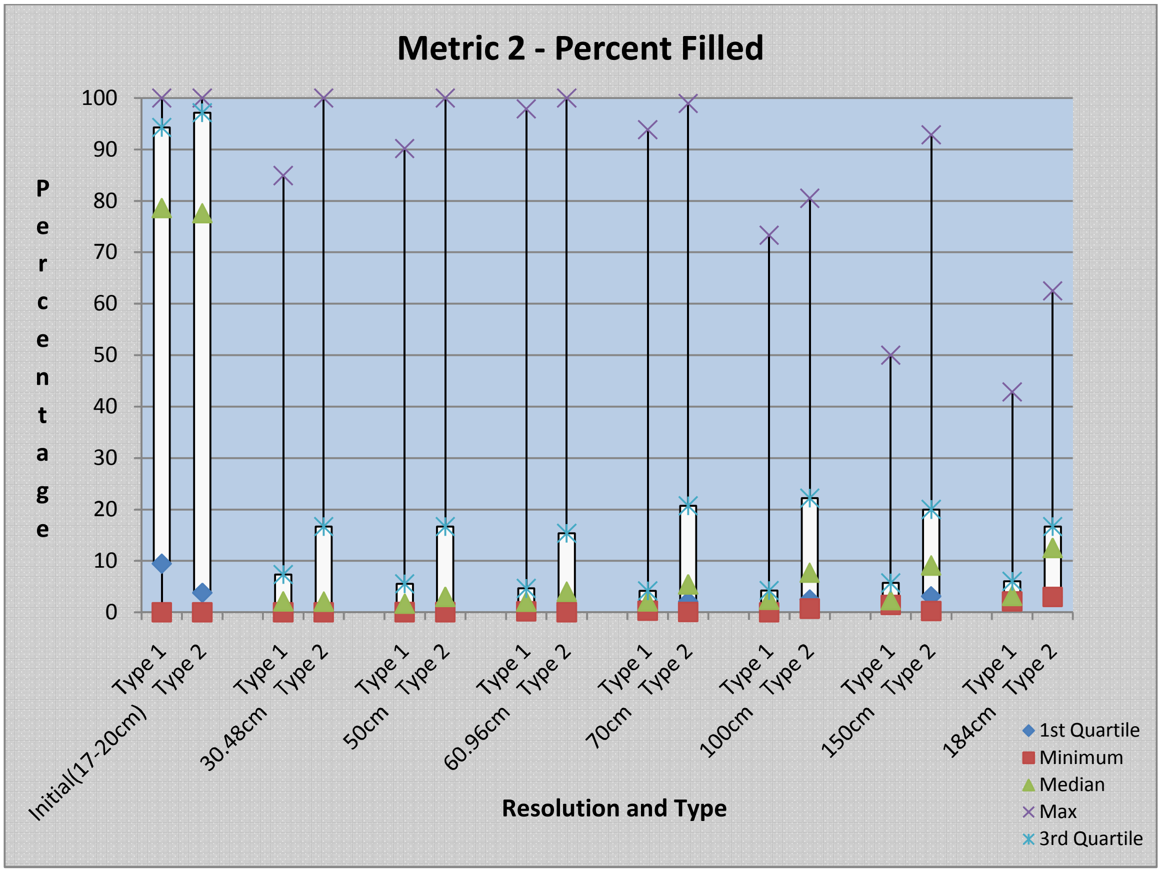


Figure 4.12 Metric 2- Percent Filled for the EDISON algorithm, separated by problem area type.

Figures 4.13 and 4.14 on the next page show EDISON segmentations of a spillway at the initial and 30.48cm resolution, respectively. An increase in the size of the segments produced is observed when comparing the two figures. Also, the total number of segments appears to be reduced in Figure 4.14. The noticeable increase in segment size observed between the first two resolutions further seems to agree with the sharp decline seen in Figure 4.12

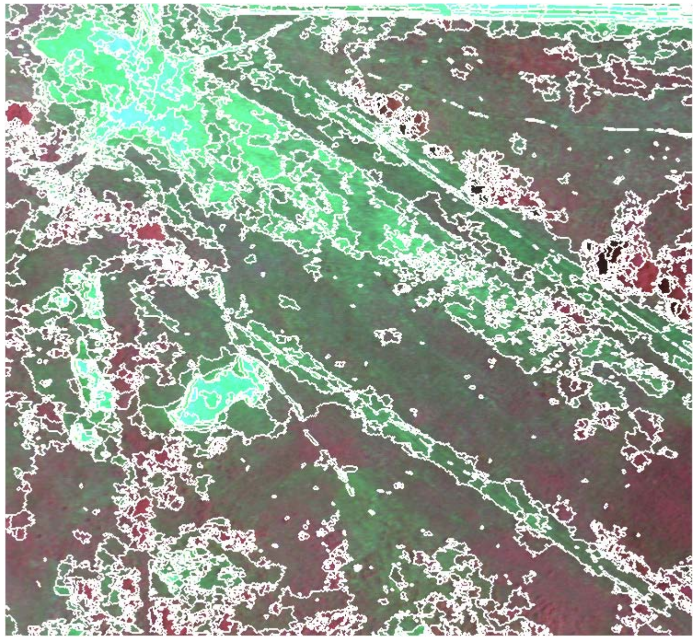


Figure 4.13 EDISON segmentation of Little Deep Fork Site 38 at initial resolution.

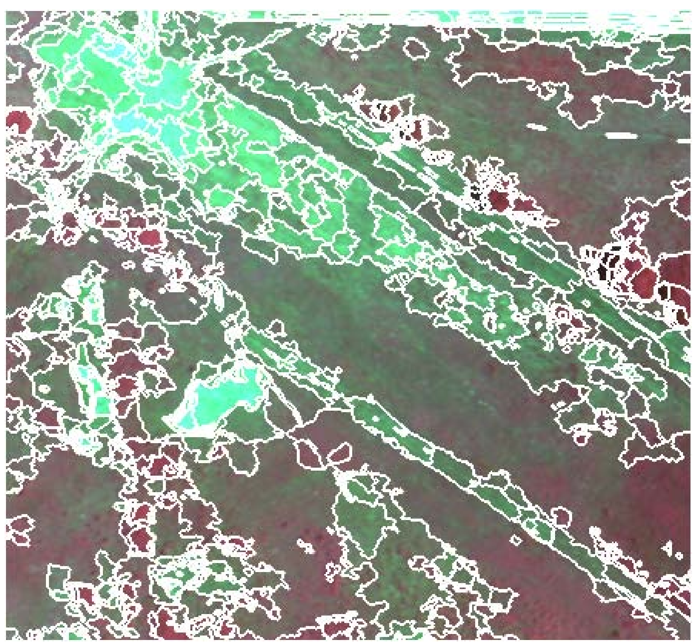


Figure 4.14 EDISON segmention of Little Deep Fork Site 38 at 30.48cm resolution. This image has been enlarged to match Figure 4.13 for viewing purposes.

CHAPTER 5

CONCLUSIONS

This thesis work has attempted to investigate the feasibility of computational detection of vegetal problem areas on earthen embankments. The four different segmentation algorithms applied to aerial images of spillways provided information as to the types of features that might be detected on a consistent basis. Visual inspection and comparison of the segmentation results reveal that the segmentation algorithms have a difficult time segmenting the regions of bare soil from the regions of sparse vegetation. This is problematic for detection purposes because areas of sparse grass are not major problem areas in many cases. Also, areas of weeds are often segmented the same as trees. This is not an issue for detection, but is an issue in real-world categorization of the type of problem area being dealt with.

Computational results show that decreasing the resolution of the image decreases the percentage of a segment containing a problem area that is segmented. Detection of some problem areas seems to be possible, but based on the experiments in this work it cannot be said for sure whether detection is possible at a satisfactory level of accuracy. Likewise, the resolution that would be required to perform detection cannot be stated for sure.

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APPPENDICES

APPENDIX A

Segmentation Parameters

A.1 EDISON Parameters

Color Threshold : 6

Spatial Threshold: 7

Minimum Region Size: 5

A.2 GPAC Parameters

TileSize: max(“image width”/50)

Phi: 2 * (TileSize)

A.3 JSEG Parameters

Number of Scales: 6

Region Mege Threshold: .4

Color Quantization Threshold: 200

A.4 Pyramid Parameters

Link Threshold: 150

Cluster Threshold: 47

APPENDIX B

Detailed Site Descriptions

Note: In this appendix, “spillway” refers to an earthen vegetated auxillary spillway.

Problem area locations are described as viewed from the spillway crest facing downstream.

B.1 Bear, Fall, and Coon Creek Site 13

Maintenance Code: 3

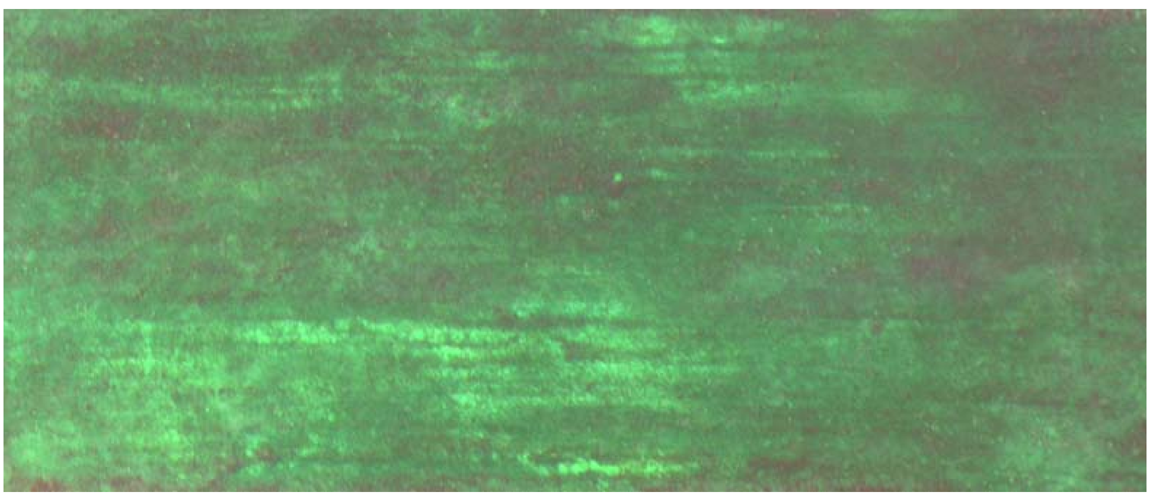


Figure B.1 Bear Fall & Coon Creek Site 13 Spillway

The spillway of this site appeared to be in good condition when viewed from a distance, but walking the spillway revealed that spillway has several issues. The most easily noticed issue is the density of the vegetal cover. Short (mostly less than six inches) and sparse grass is the only protection for the majority of the spillway. Darrel and Greg describe the condition of the vegetation by a cover factor of near zero, which means the vegetation will provide little protection against spillway flow. Notwithstanding other discontinuities, the condition of the vegetation puts this spillway into maintenance category 2.

Numerous small bare areas and three to four bare areas larger than 10 ft in length push this spillway into a maintenance category 3. The areas of bare earth most likely are developing as the result of local spillway runoff.

Trees and other woody plants are not an issue on this spillway. The only trees near the spillway are outside the spillway berms and below the spillway exit. Mowing and/or grazing have kept the spillway free from trees or shrubs of any size.

B.2 Bear, Fall, and Coon Creek Site 11

Maintenance Code: 3

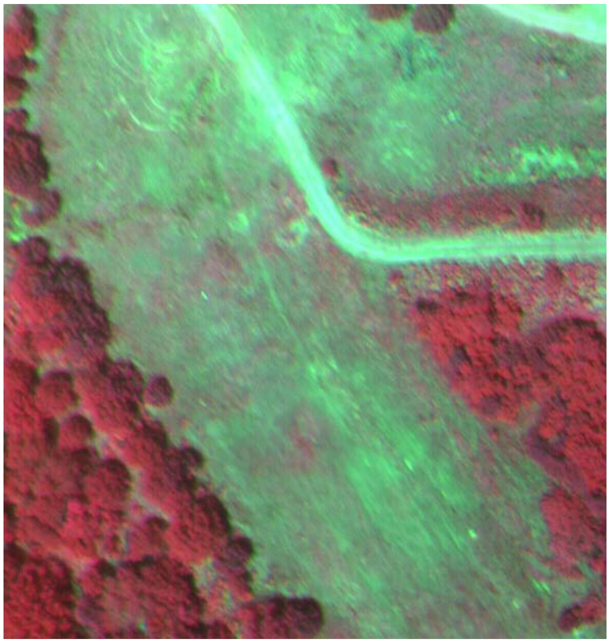


Figure B.2 Bear Fall & Coon Creek Site 11 Spillway

Bear Fall and Coon Creek Site 11 has several major discontinuities that make it one of poorer maintained sites that were photographed. The area near the spillway exit contains a large gully that is as wide as the spillway floor and greater than 10 feet deep. This Problem area is in immediate need of repair because a spillway flow might lead to the breach of the dam.

The vegetation on this spillway is thick for the most part. Grass and weeds are mixed throughout the spillway, and stem lengths mainly range from 6 to 12 inches. Overall there are no vegetal cover features of major concern when compared to the gully near the exit.

Several small cedar trees less than 5 feet tall are growing halfway down the length of the spillway. Though these trees are small, their close proximity to one another forms a large Problem area that would concentrate flow to other areas of the spillway in and emergency flow. Also, several larger trees are growing near the exit of the spillway. These trees are also a major Problem area in the spillway.

B.3 Stillwater Creek Site 26

Maintenance Code: 1

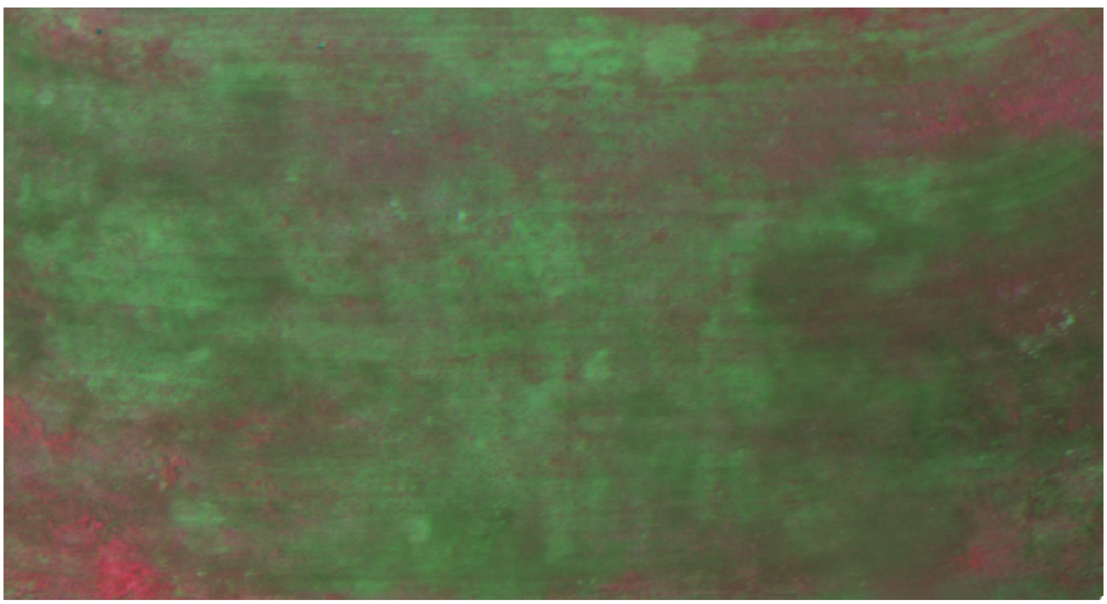


Figure B.3 Stillwater Creek Site 26 Spillway

Stillwater Creek Site 26 is the best-maintained spillway of all the spillways that were photographed. The vegetation is of uniform height and density throughout the spillway. This spillway has been maintained by the city of Stillwater and is mowed regularly during the summer. Even though the cover is uniform, Darrel and Greg note that there is room for improvement on the quality of the vegetation.   The vegetation is not as thick as the vegetation on some of the other sites, and though there is no area of this spillway that is markedly weaker than the rest, a thicker, healthier vegetal cover would definitely enhance the protection of this spillway.

B.4 Stillwater Creek Site 28

Maintenance Code: 3

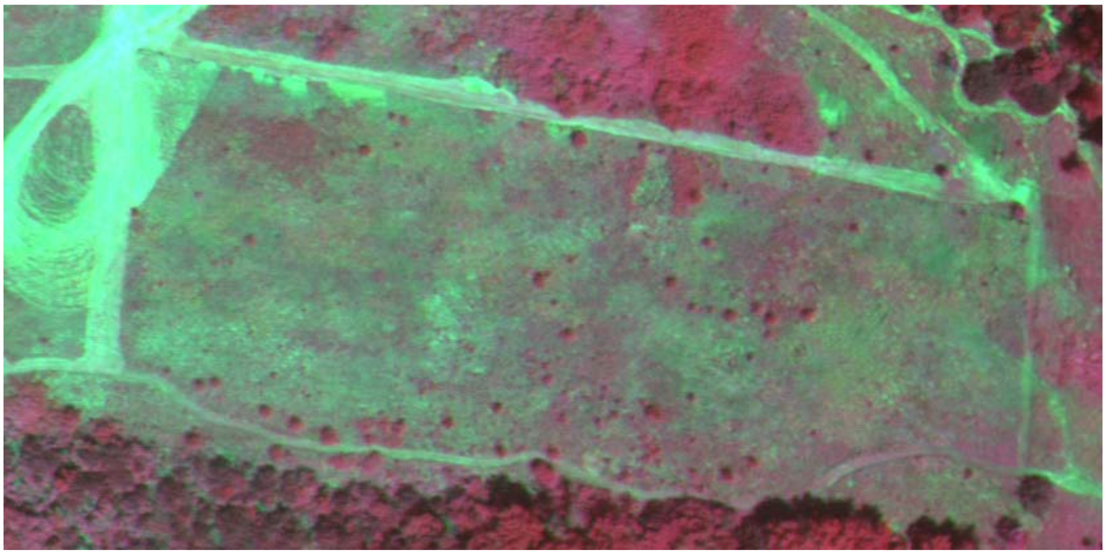


Figure B.4 Stillwater Creek Site 28 Spillway

Stillwater Creek Site 28 is located near a residential neighborhood, and someone has mowed a walking trail down the length of the spillway. The vegetation in the trail is much shorter than any in the spillway. This is a problem because it creates an area of flow concentration, and because of the length and orientation of this trail, it is considered a major Problem area.

The vegetation in the remainder of the spillway varies greatly from one area to the next. Grass with stem length greater than six inches is common throughout the spillway, but infestations of weeds and brush make the cover on this spillway far from uniform. A large area of thick brush along the left side of the spillway will concentrate flow around it and is a major Problem area.

Aside from one small area midway down the left edge of the spillway, there are no areas of bare earth or evidence of erosion already in process.

Numerous small trees litter the floor of the spillway from the crest to the exit. The mid section of the spillway has the highest density of small trees. A group of seven these trees near the centerline of the spillway are growing in a line parallel to the length of the spillway and because of this the group is considered a major Problem area. Another group of small trees growing along the right bank forms a Problem area that is large enough to be considered major. There are a few larger trees along the bank of the spillway, each of these are minor discontinuities.

B.5 Stillwater Creek Site 29

Maintenance Code: 3

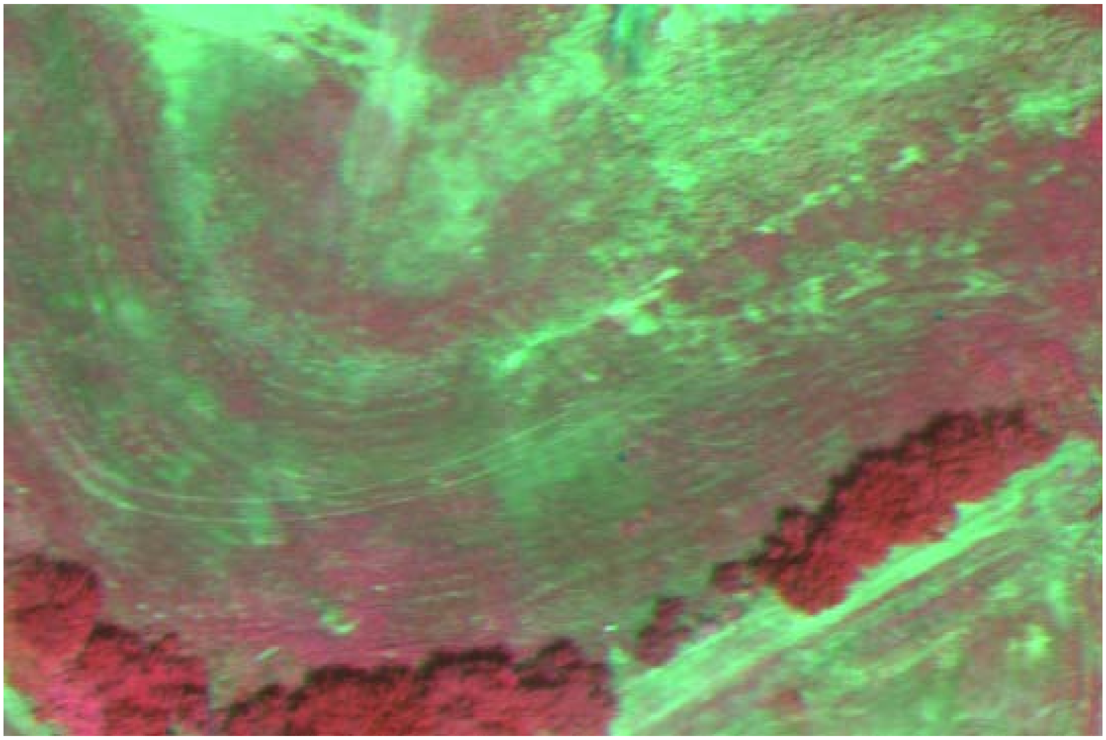


Figure B.5 Stillwater Creek Site 29 Spillway

Along the left side of this spillway near the exit is a large area of small trees that extends from the bank to just past the centerline of the spillway floor. This group of trees is a major problem and classifies the spillway as a maintenance code 3.

Vegetation throughout the spillway is weak. In the area near and just below the crest, the vegetation consists of very short fine-bladed grass. The vegetation becomes thicker and taller near the midsection of the spillway and from that point on becomes troubled by weeds and small patches of brush. None of these vegetal features fall into the major Problem area category.

Construction waste material has been dumped in the spillway near exit on the right side of the spillway, and the waste forms several large mounds. These mounds form a major Problem area that restricts the ability of flow to exit the spillway along the right side and force flow toward the left dike of the spillway. A vehicle trail leading from the dump site up the length of the spillway and over the crest is also a major issue of concern. Parts of this trail contain deep ruts that will be an immediate cause of erosion during a spillway flow.

B.6 Little Deep Fork Site 38

Maintenance Code: 3

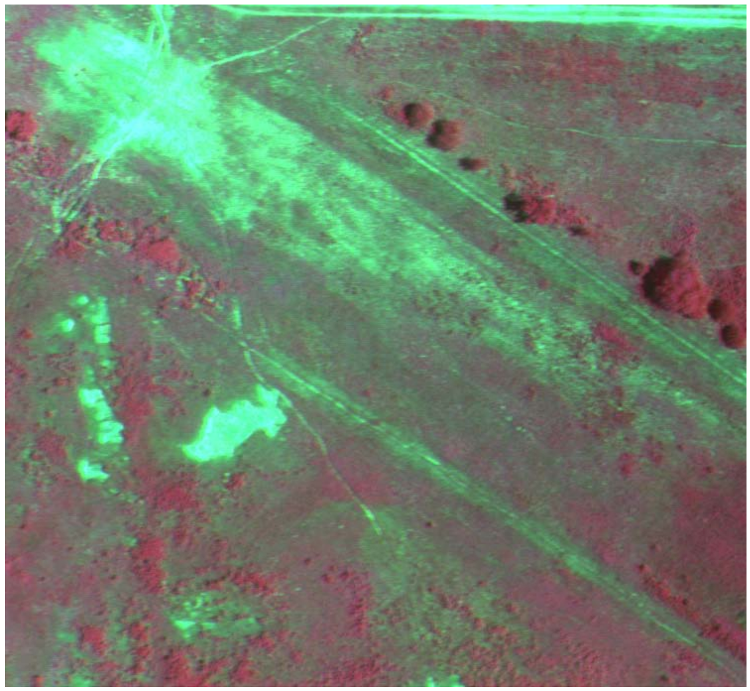


Figure B.6 Little Deep Fork Site 38 Spillway.

Little Deep Fork Site 38 had a spillway flow one month prior to the visit to the site. This spillway flow caused a major erosion feature, but the upper edge of the feature is yet to advance up into the spillway so it was not considered as part of the evaluation of the spillway.

The vegetation is very different on the left half of the spillway than that on the right half. These two distinct areas of dissimilar vegetation create a major Problem area due to the fact that the left area contains shorter, weaker vegetation which will cause flow to concentrate toward the left area.

Areas of bare earth are also a concern on this spillway. Near the crest, two cattle trails cross the width of the spillway. The trails are void of vegetation but are not major discontinuities because the dimension parallel to flow is only about 8 inches for each trail. Other areas of bare earth litter the left side of the spillway beginning approximately 150ft downstream of the crest and continue through the spillway exit. These areas along the left side of the spillway consist of holes that were possibly created by the erosion of rodent tunnels during the spillway flow. Near the exit, ruts have been made by a vehicle driving down the length of the spillway. The ruts are void of vegetation and long enough to be considered a major Problem area.

B.7 Salt Camp Creek Site 6

Maintenance Code: 2

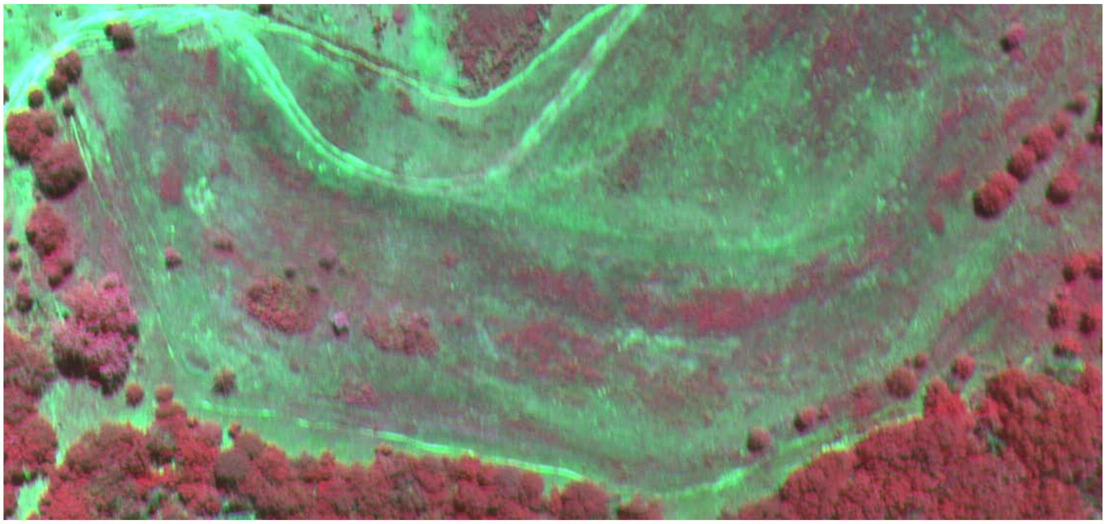


Figure B.7 Salt Camp Creek Site 6 Spillway

The spillway at Salt Camp Creek Site #6 is in moderate condition. Several minor discontinuities keep this spillway from being categorized as a maintenance code 1, but it is in much better condition some of the other spillways that were photographed. The vegetation throughout the spillway is adequate and there are no areas of bare earth large enough to be considered major discontinuities.

The main reason why this spillway is classified as a maintenance category 2 is the presence of trees in the lower reach of the spillway. Several trees line the right bank and one tree is growing near the centerline of the spillway. The trees are separated from one another and small enough that none are considered major discontinuities.

B.8 Robinson Creek Site 2

Maintenance Code: 1

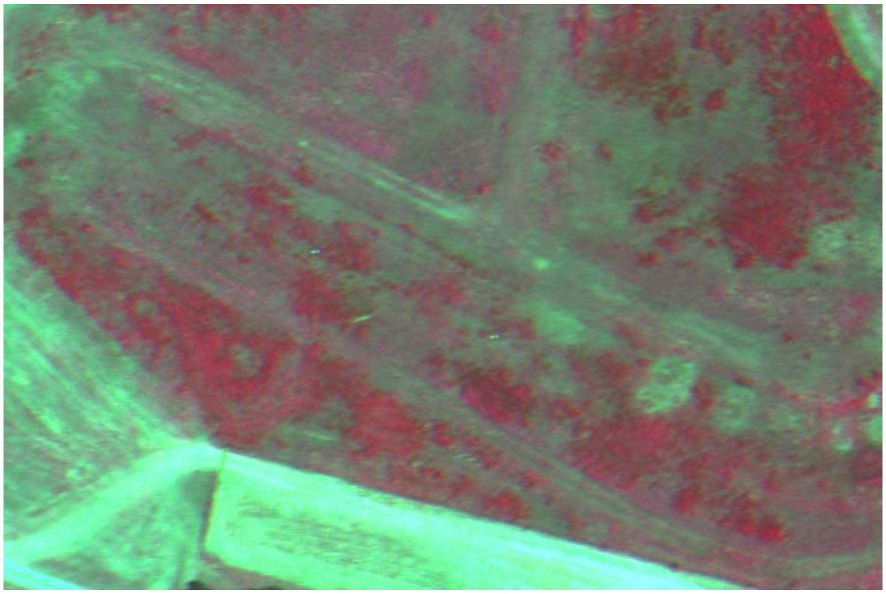


Figure B.8 Robinson Creek Site 2 Spillway

Robinson Creek Site #2 is well-maintained and would rank second-best among the sites that were photographed. The vegetation is uniform and greater than six inches in height over the majority of the spillway. There are no trees or areas of bare earth in the spillway. A cattle trail is discernable going up the left side of the spillway berm, but it disappears as it enters the floor of the spillway. The only issue that this spillway has is a possibility of a future problem with an infestation of sericea lespedeza.

B.9 Quapaw Creek Site 16

Maintenance Code: 2

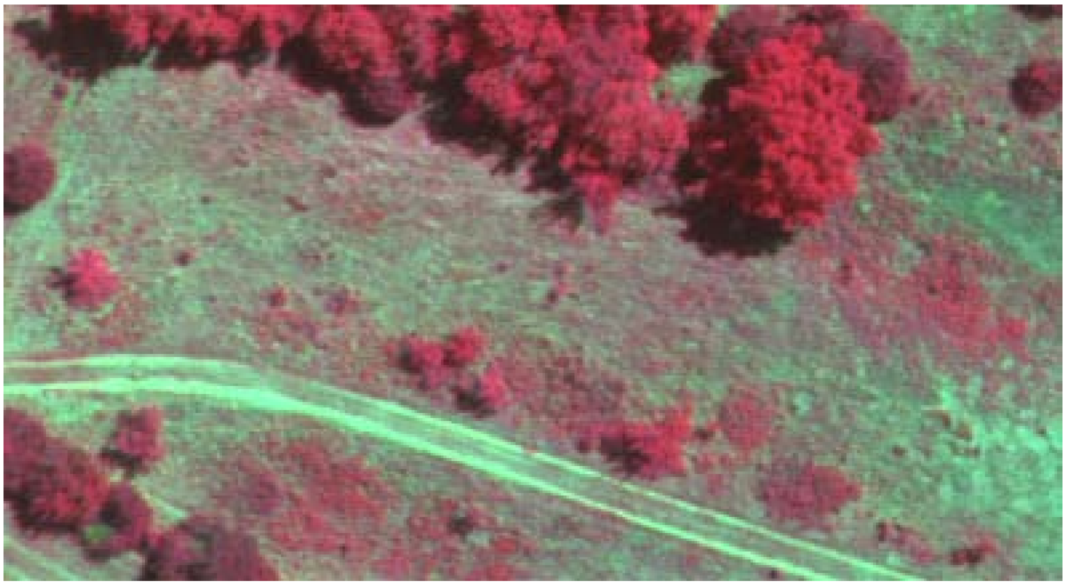


Figure B.1 Quapaw Creek Site 16 Spillway

Quapaw Creek Site #16 is the smallest of the spillways photographed, and it has no major issues. The vegetation is overgrown and not maintained, but it is mostly uniform and is very thick so it does provide adequate protection. There are no areas of bare earth, trails, or ruts discernable from the visit to the site.

The reason this spillway is classified with a maintenance code 2 is the presence of small trees in the spillway. There are several small trees near the left bank of the spillway and one small cedar tree in the center of the spillway. Each of these trees is a minor Problem area. Another larger tree along the right bank near the midsection of the spillway is close to being a major Problem area and if it were a major Problem area then this spillway would be knocked down to a maintenance code 3.

B.10 ARS Hydraulic Lab

Maintenance Code: 3

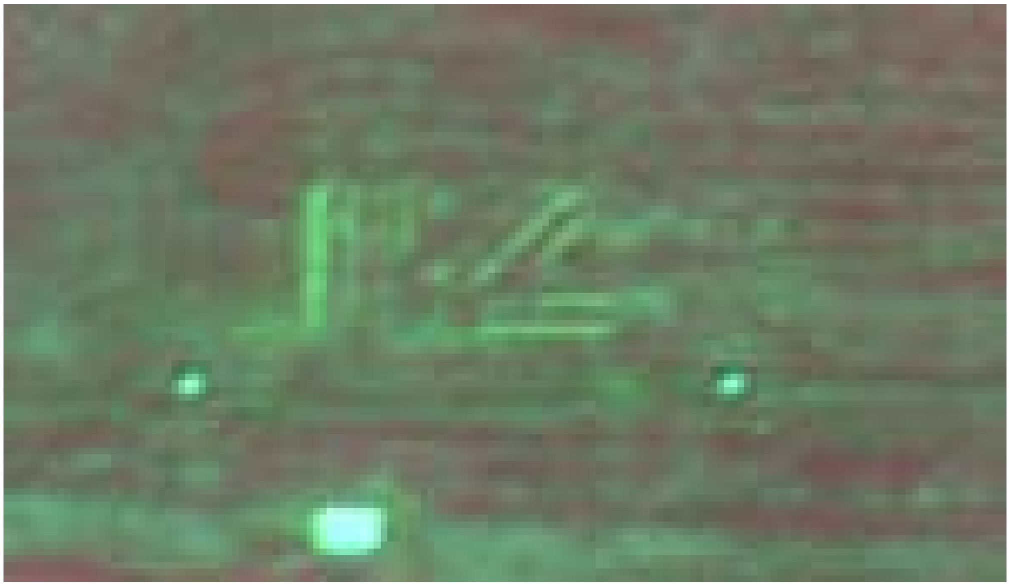


Figure B.10 ARS Hydraulic Lab Image

This image is taken of a location that was manually created by digging bare soil discontinuities in a well-vegetated area on the grounds of the ARS Hydraulic Lab. Three vertical strips of varying widths (24 inches,12 inches, and 9 inches) were dug as well as two horizontal strips, two diagonal strips, a 1ft square, and a 2ft square. In all the location contains 6 major discontinuities and 4 minor discontinuities.

APPENDIX C

Description of Vegetal Maintenance Code

The vegetal maintenance code is a metric used to describe the condition of a spillway. Based on visual inspection, a spillway can be assigned one of the three codes described below. These codes together make up a classification system for onsite visual inspections that allows inspectors to group spillways according to their condition, which facilitates the process of repairing poor spillways.

Code 1: Uniform cover, no discontinuities are observable from an on-site visual inspection. Spillways with a maintenance code of 1 are in good condition and would be expected to perform as designed in the event of spillway water flow.

Code 2: Only minor discontinuities are observable. Minor discontinuities are those discontinuities having length (dimension parallel to spillway flow) no greater than the average stem length of the vegetation. A spillway with this maintenance code needs work to prevent the minor discontinuities from growing to major problem.

Code 3: Major discontinuities are observable. Major discontinuities are those discontinuities having length (dimension parallel to spillway flow) greater than the average stem length of the vegetation. Note that any size tree falls in to this category. Spillways with maintenance code 3 need immediate repair. A spillway flow event on these spillways could cause significant damage to the spillway and the flood control structure.

APPENDIX D

Camera and Image Collection Information

Manufacturer: Duncan Tech

Model: MS4100s

Resolution: 1920x1080 pixels

Pixel Size: 7.4 x 7.4 micron

Filters: 3-Band (Red, Green, Near-Infrared)

Signal/Noise: 60dB

Flight Date: July 8th 2008

Pilot: Bob Bailey

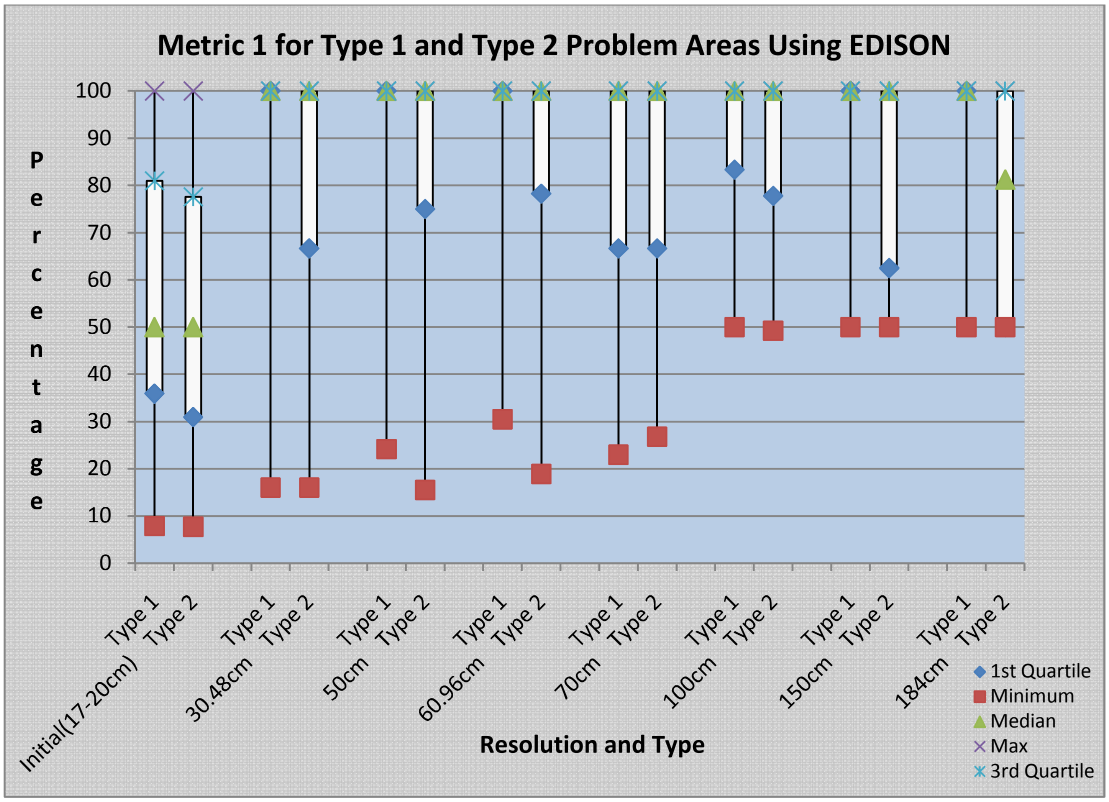
Photographer: Warren Thetford

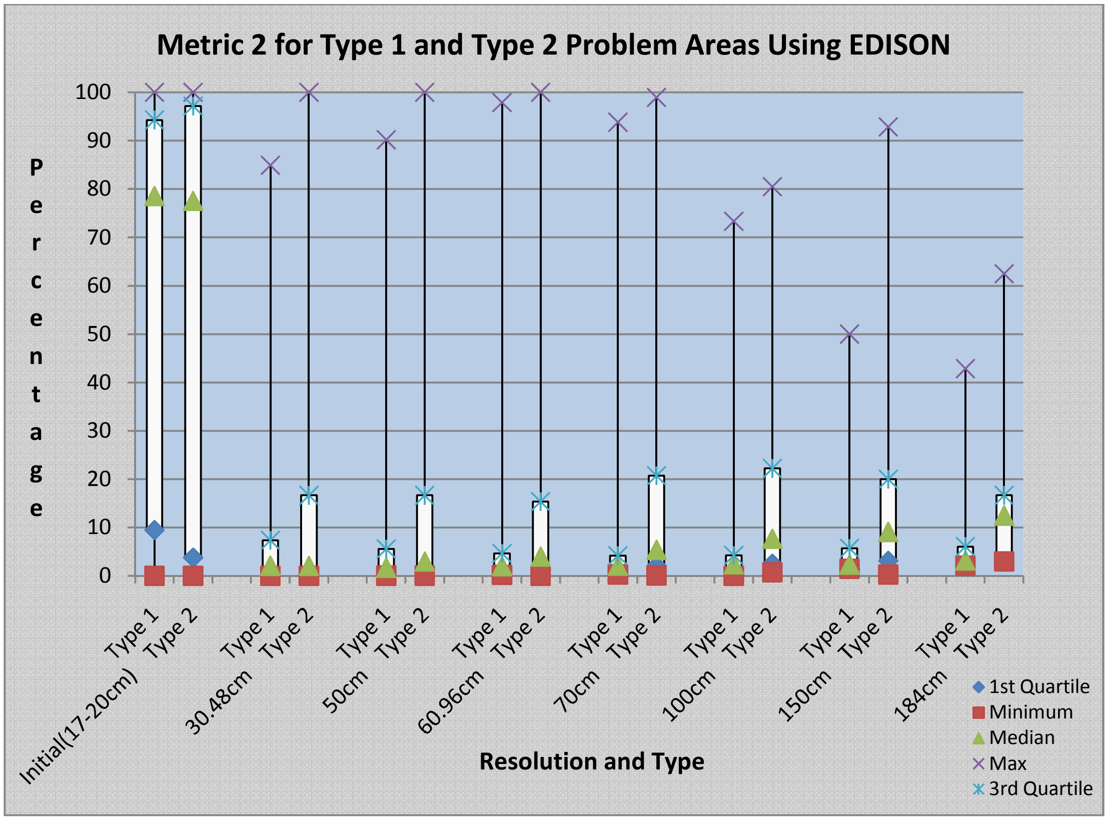
Company Name: Precision Brush Control

Website: http://www.precisionbrushcontrol.com/

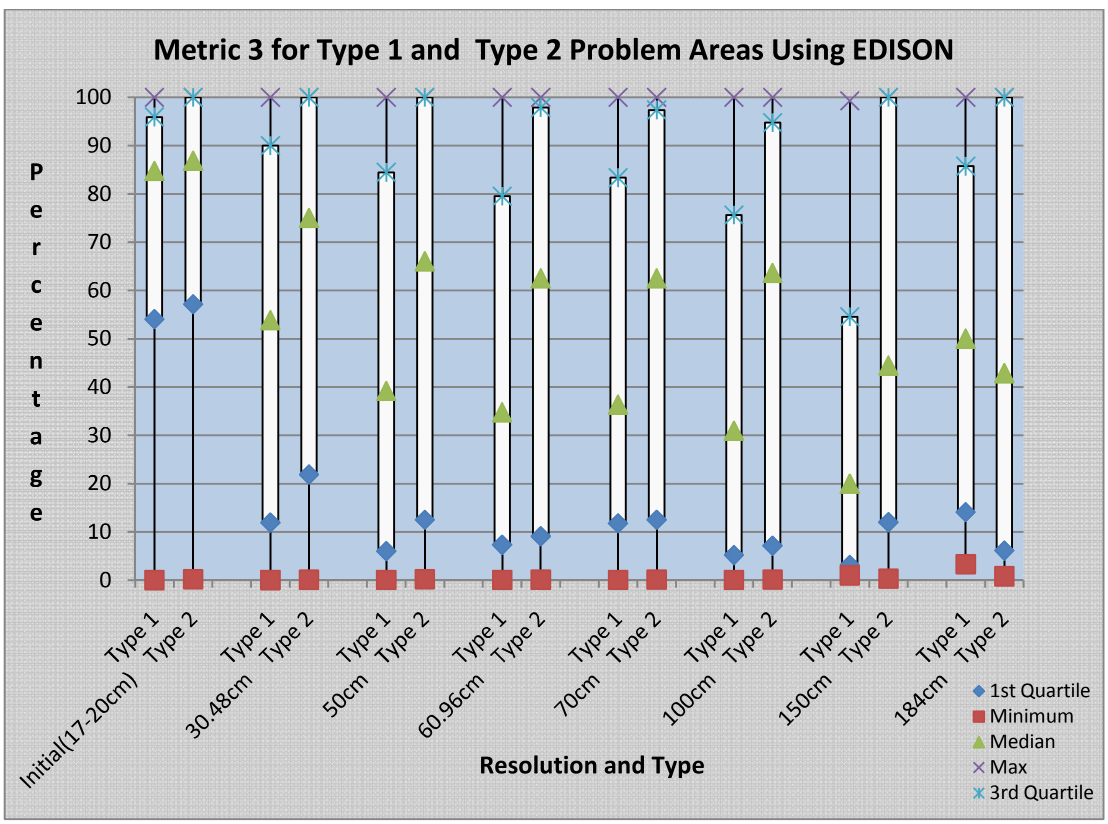
APPENDIX E

Result Charts

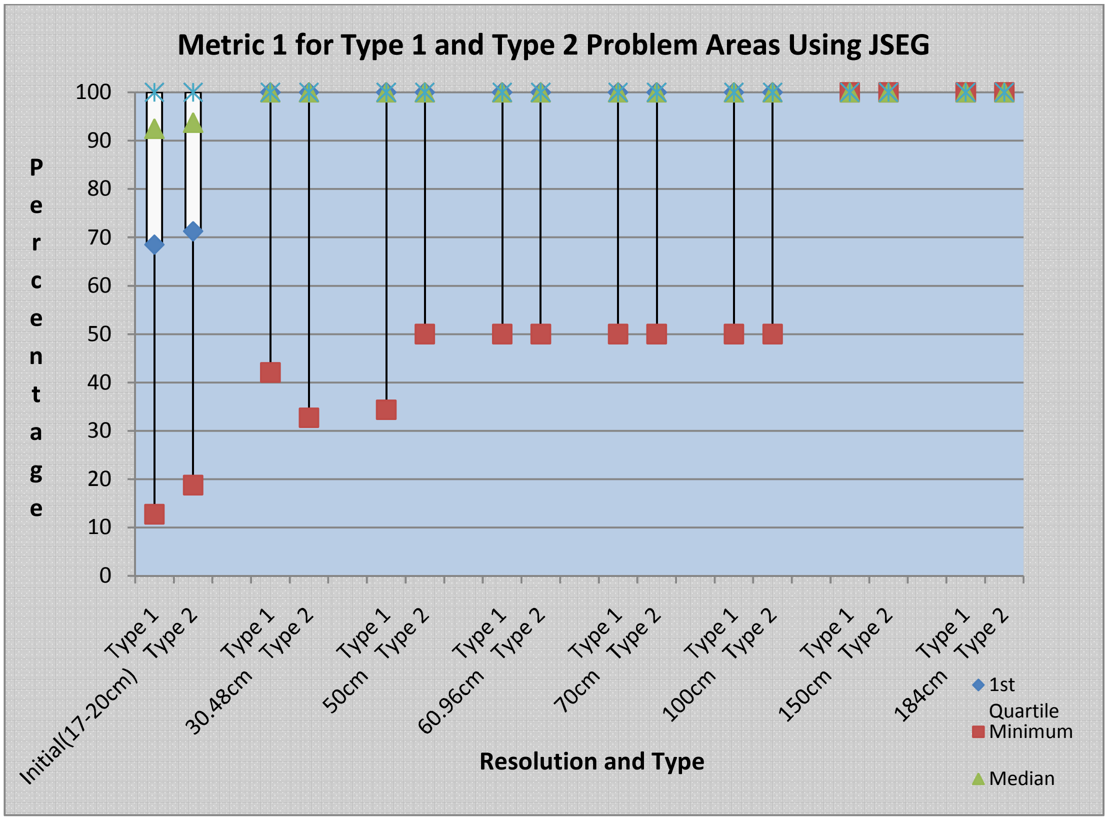


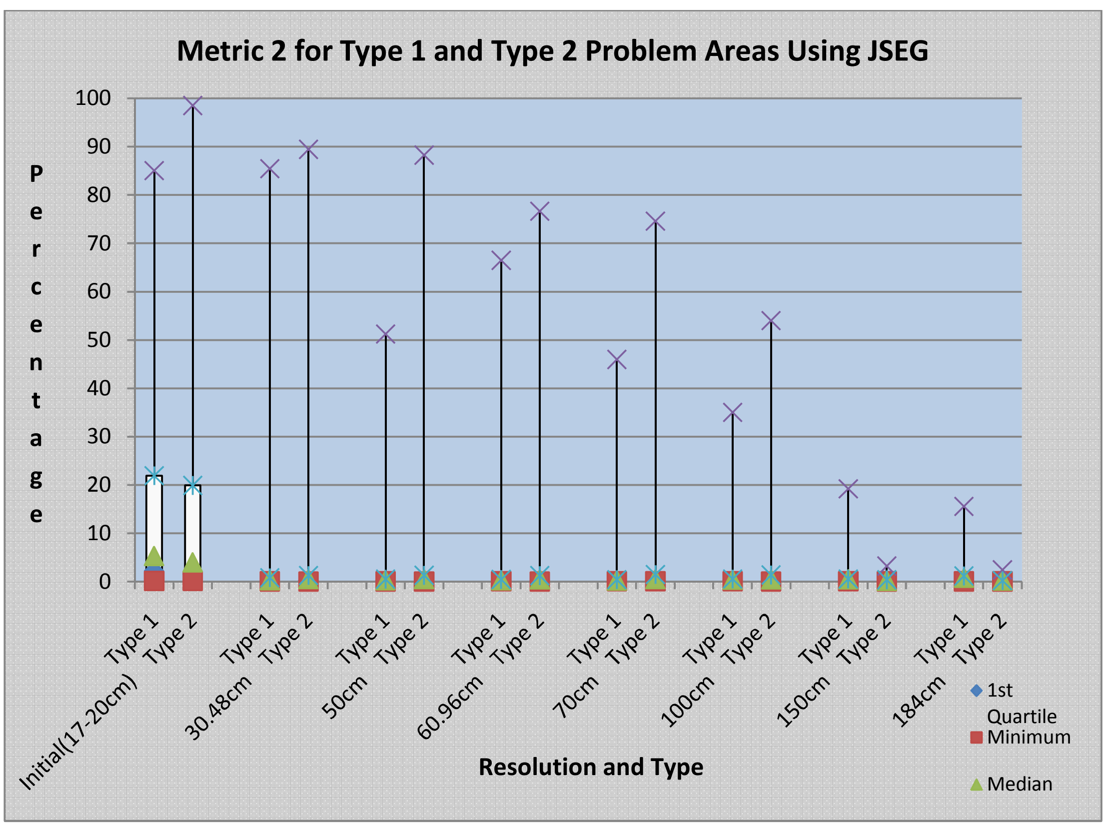


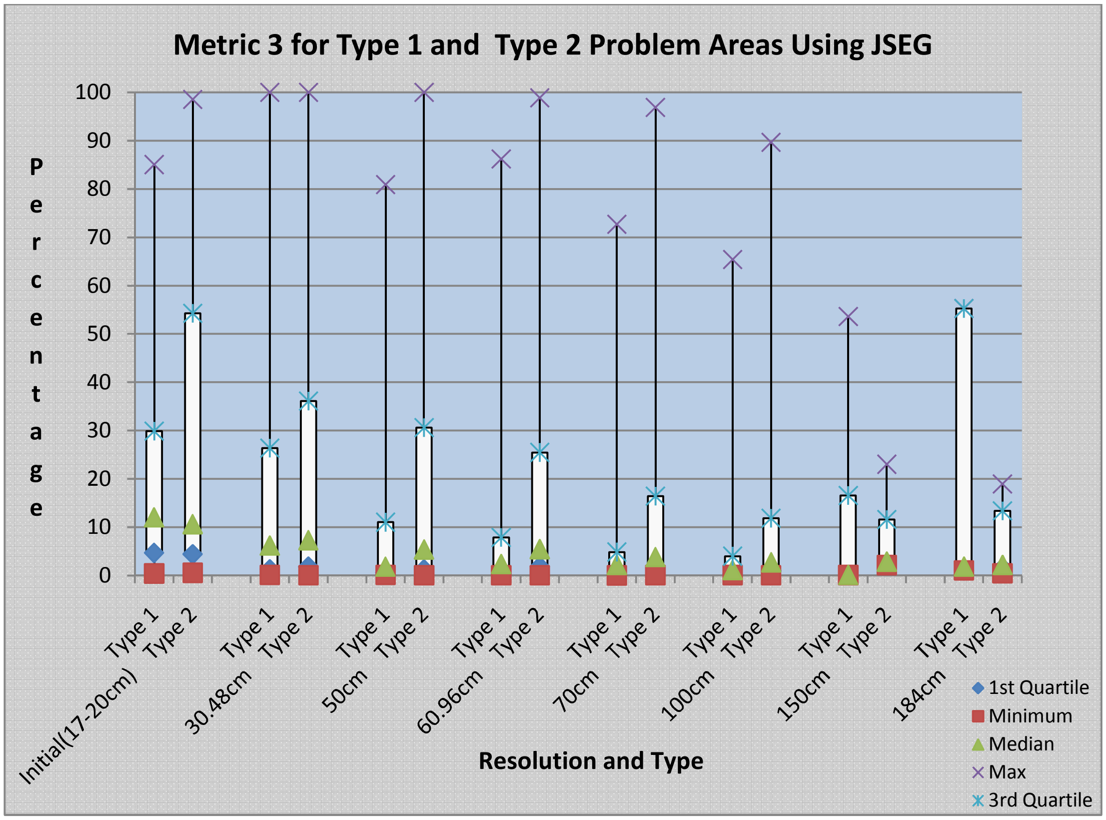
Metric 2 for Type 1 and Type 2 Problem Areas Using EDISON
Percentage
100
90
80
70
60
50
40
30
20
10
0
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median
Max
3rd Quartile

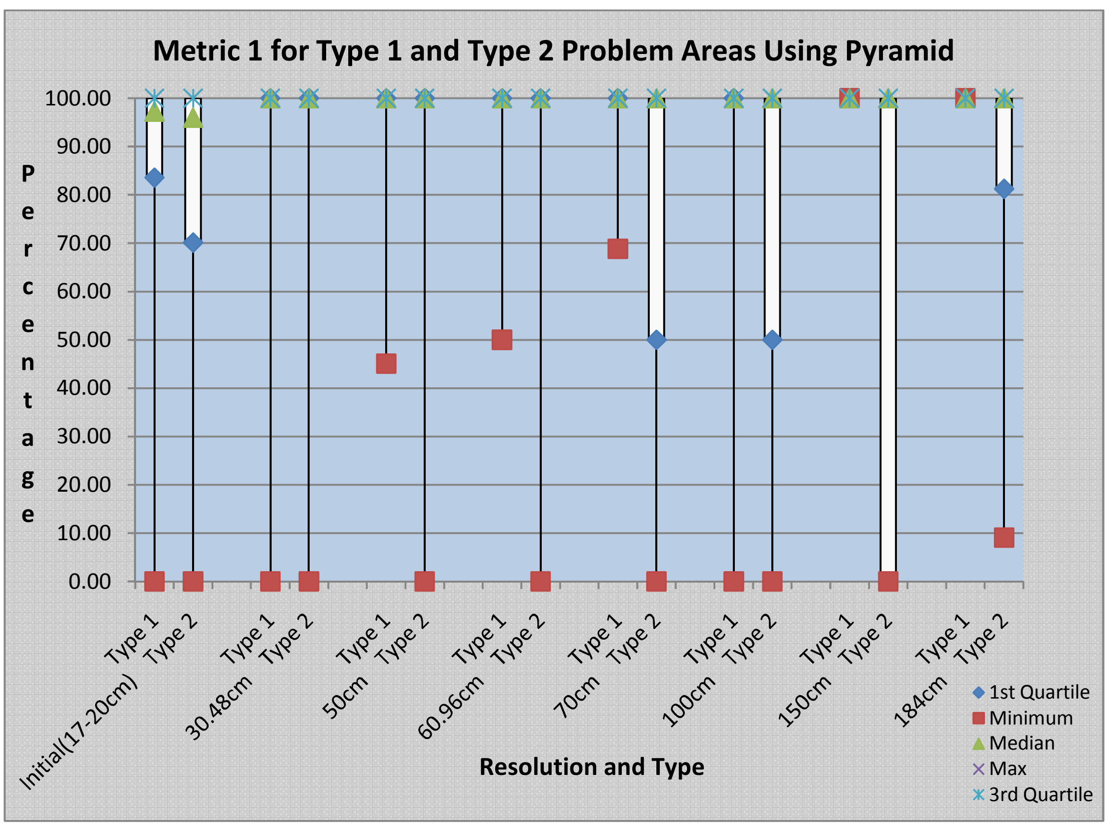


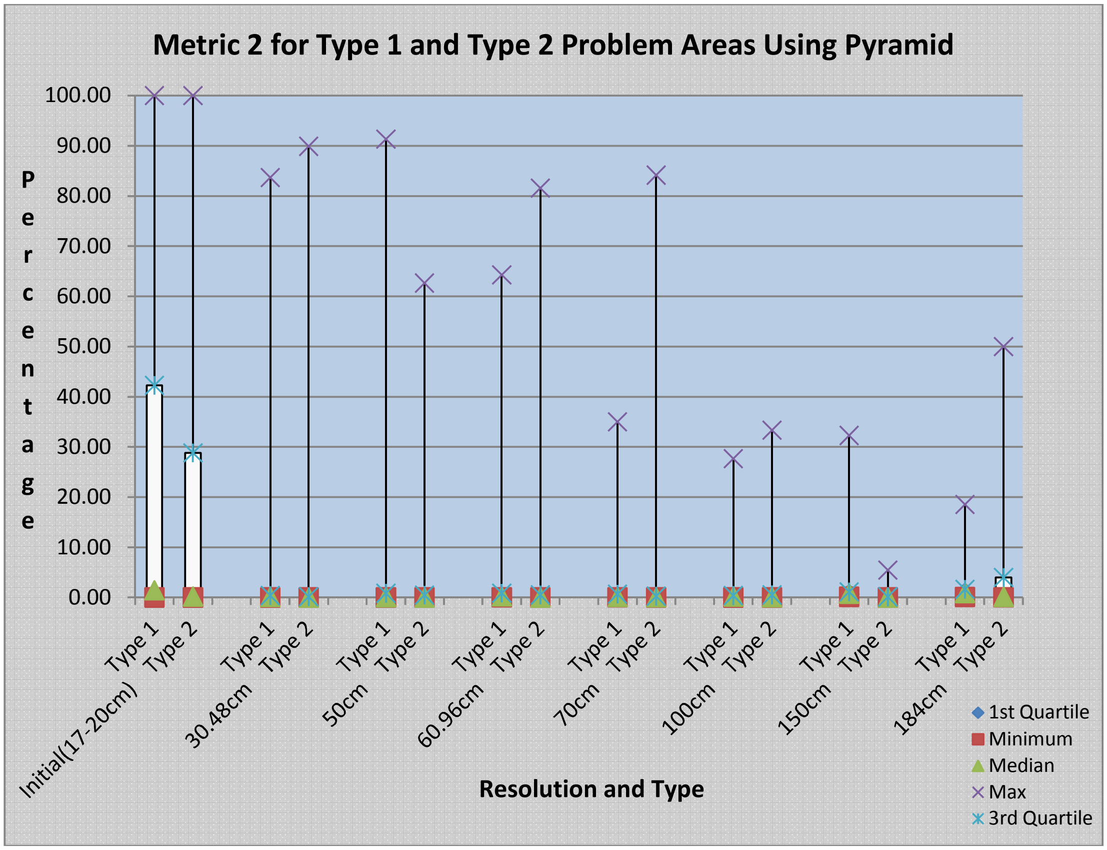
Metric 3 for Type 1 and Type 2 Problem Areas Using EDISON
Percentage
100
90
80
70
60
50
40
30
20
10
0
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median
Max
3rd Quartile

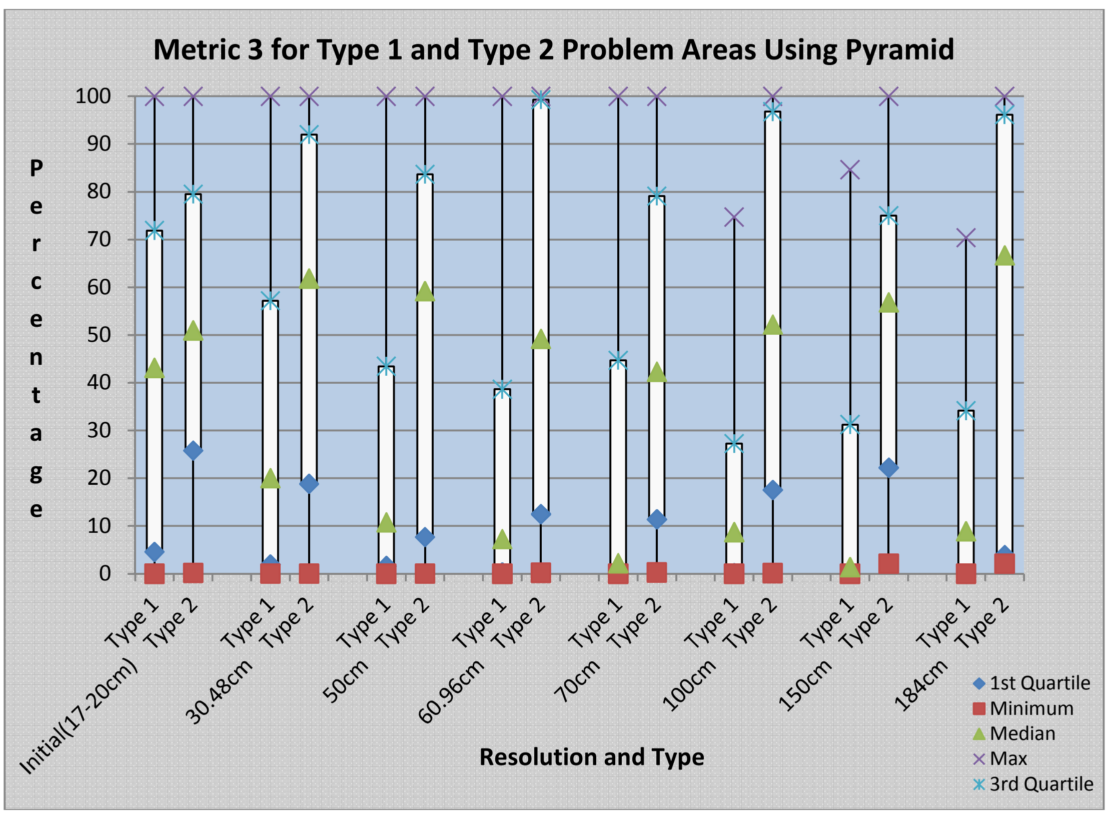

Metric 1 for Type 1 and Type 2 Problem Areas Using JSEG
Percentage
100
90
80
70
60
50
40
30
20
10
0
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median


Metric 2 for Type 1 and Type 2 Problem Areas Using JSEG
Percentage
100
90
80
70
60
50
40
30
20
10
0
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median


Metric 3 for Type 1 and Type 2 Problem Areas Using JSEG
Percentage
100
90
80
70
60
50
40
30
20
10
0
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median
Max
3rd Quartile


Metric 1 for Type 1 and Type 2 Problem Areas Using Pyramid
Percentage
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median
Max
3rd Quartile


Metric 2 for Type 1 and Type 2 Problem Areas Using Pyramid
Percentage
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median
Max
3rd Quartile


Metric 3 for Type 1 and Type 2 Problem Areas Using Pyramid
Percentage
100
90
80
70
60
50
40
30
20
10
0
Type 1
Type 2
Initial(17-20cm)
30.48cm
50cm
60.96cm
70cm
100cm
150cm
184cm
Resolution and Type
1st Quartile
Minimum
Median
Max
3rd Quartile

VITA

Kevin L Cole

Candidate for the Degree of

Master of Science

Thesis: INVESTIGATION OF COMPUTATIONAL PROBLEM AREA DETECTION ON EARTHEN SPILLWAYS ACROSS VARYING IMAGE RESOLUTIONS

Major Field: Computer Science

Biographical:

Education:

Completed the requirements for the Master of Science in Computer Science at Oklahoma State University, Stillwater, Oklahoma in July, 2010.

Completed the requirements for the Bachelor of Science in Computer Science at Oklahoma State University, Stillwater, Oklahoma in May, 2005.

Name: Kevin Cole Date of Degree: July, 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INVESTIGATION OF COMPUTATIONAL PROBLEM AREA DETECTION ON EARTHEN SPILLWAYS ACROSS VARYING IMAGE RESOLUTIONS

Pages in Study: 59 Candidate for the Degree of Master of Science

Major Field: Computer Science

This thesis work investigates the ability of segmentation algorithms to segment vegetal problem areas in aerial images of earthen spillways. Four different segmentation algorithms were applied to aerial images of spillways that were resized to 8 different resolutions. Segmentation results from each algorithm and spillway resolution were analyzed on the basis of the percentage of pixels segmented for each problem area using a manually segmented image as a ground truth for comparison.

ADVISER'S APPROVAL: Dr. Douglas Heisterkamp