RISK ASSESSMENT REPORT

Prepared for

City of Boulder

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HDR Engineering, Inc.

CH2MHILL

DHI WATER & ENVIRONMENT

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RISK ASSESSMENT - DRAFT

1.0 INTRODUCTION

The purpose of the risk assessment along South Boulder Creek is to assess the level of risk associated with floods and to help provide a framework for future mitigation efforts. This framework defines the extent of the flood hazard, the frequency of flood threats to properties within the identified flood hazard, and a better understanding of how floods propagate through the basin. Together, this information will help guide City staff and the public through the difficult decision making process that will determine when and how future flood mitigation investments should be made.

Many of the evaluations incorporated into the risk assessment are based on the Hydrology Advisory Panel (HAP) recommendations. The HAP was a group of technical experts convened in 2002 to support of the City's efforts in determining the flood hazard along South Boulder Creek. Their recommendations included specific recommendations for elements that should be included in the risk assessment as well as several of the other scope elements of the study.

HAP's recommendations include a summary of the motivation for the risk assessment which included the following narrative:

"Management of flood risks involves a developing clear understanding of the flood problem. The risk assessment should provide a framework for defining the problems with flooding to inform and educate the public. Analysis of the watershed hydrology and floodplain hydraulic modeling provides the basis to evaluate risks to various areas, properties, infrastructure and buildings."

In addition to the approaches intimated by HAP, an element of risk assessment is already a strong part of the City's floodplain management program. The City has a longstanding commitment to proactive floodplain management. While this study focuses on the identification of the flood hazard along South Boulder Creek, an earlier estimate of the floodplain and associated hazard is already in place. These regulatory tools have already been adopted along South Boulder Creek and will be updated by this study.

The regulatory controls are defined in the Boulder Revised Code 1981, and more specifically in Title 9 – Land Use Regulations.

1.1 FLOODPLAIN DELINEATIONS

Floodplain delineations provide the most fundamental assessment of flood risk. The City defines floodplains as "the area that is inundated by a flood". These are relatively straight forward and depict the area inundated by a flood having a given probability of occurrence during any given year. The 100-year flood (probability of 1% in any given year) is the most common regulatory standard and is the common basis for flood inundation risk. The City has adopted the previously defined 100-year floodplain and regulates accordingly. It is the City's intention to regulate to the 100-year floodplain delineated in this study.

1.2 CONVEYANCE ZONE

The City has adopted a standard definition of the conveyance zone to further define areas of high flood risk. The conveyance zone is defined by the City as "those portions of the floodplain required for the passage or conveyance of the one hundred-year flood based on equal encroachment (measured in volume of water) of the floodplain from the edges of the flood channel to a point where the one hundred-year flood profile will be raised by six inches or more, after considering a reasonable expectation of blockage at bridges and other obstructions by flood borne debris". This definition is the basis for the current zone. The foundation for the determination arrived at during the current study uses a slightly more pragmatic approach and focuses on the designation of the area necessary for the passage or conveyance of the one-hundred year flood without the constraint of equal encroachment but rather trying to take full advantage of existing open space and public rights-of-way.

1.3 HIGH HAZARD ZONE

The City has also adopted a higher level of flood hazard definition called the high hazard zone. This zone has been defined as "those portions of the floodplain where an unacceptably high hazard to human safety exists defined as those areas where the product number of flow velocity (measured in ft./sec.) times flow depth (measured in feet) equals

or exceeds four, or where flow depths equal or exceed four feet". Here again, a current high hazard zone is in place and will be superseded by the results of this study.

2.0 MEASURES OF RISK

The City recognizes that the existing regulatory measures of risk, while effective for regulatory purposes, may not clearly define the entire spectrum of hazards. As such, the current study of South Boulder Creek incorporates a number of additional risk factors that are to be assessed.

2.1 REGULATORY

Regulatory risk has been comprehensively addressed by the City through their Revised Code. In this, they define certain measures of risk and impose certain constraints based on the identified risk. These constraints may include development restrictions or land use limitations. Additional regulatory controls may be imposed by the federal government, such as the need to obtain flood insurance when structures within the designated floodplain are financed by a federally backed mortgage.

2.2 ECONOMIC

Economic risk is less formally defined. For the purpose of this study, economic risk is related to the expected damage to structures and contents. Several different measures of damage are adopted including event specific damages, weighted event specific damages and average annual damages. Damages expected during specific events are, as the name suggests, the level of damage expected for an event having a specified recurrence interval.

The weighted damage addresses the probability of certain damages occurring by weighting the computed damages by the probabilityof a given flood occurring in any year. In this way, the economic impact felt at structures that may have a lower assessed value, but which are flooded more frequently than a higher value structure, will be identified.

Finally, average annual damages predict the annualized damage to a specific structure. This is determined by assessing the potential damage across the full spectrum of events and determining what the damages would be if averaged over time.

2.3 ENVIRONMENTAL

Environmental damages, for the purposes of the South Boulder Creek study, are damages to channels and overbank areas that may result from exposure to flooding. The scope of the work precludes a comprehensive inventory of floodplain resources that might be impacted nor does it allow a precise determination of the types and range of conditions that might cause damage. However, it was concluded that velocity and depth could be used as surrogates for conditions that would have the potential to endanger the natural environment. As such, areas of high velocity and depth are identified and form the basis for the assessment of environmental risk.

2.4 PUBLIC SAFETY

Determination and management of the public's risk is at the heart of this, or any, floodplain study. All the previously identified measures assess the risk to the public to some extent. However, the City recognizes that an important flood management strategy available to them is that of warning. Maximizing the warning time of an impending flood given to citizens may be the most effective way to save lives and protect the public. To better understand the available warning time, an estimate of the time it takes for the front of the flood wave to travel downstream is provided.

3.0 PROCESS

Performing the risk assessment requires few new simulations; rather it builds upon existing data developed during the course of the study or from publicly available sources. The existing data includes areas of inundation and depths at all locations across the floodplain. Information available to conduct the risk assessment also includes velocities at all locations. This important hydraulic information establishes the baseline information necessary for a majority of the evaluations.

These data sets require additional synthesis to create information that can be used in the risk assessment. In most cases, the manipulation of the existing data is performed using GIS tools and does not require new hydraulic simulations.

Some new work efforts are required. The primary new data set is information specific to each structure. Information is assembled to characterize each structure and its value. Field visits were made to capture the elevation of the first floor of the structure relative to the adjacent ground elevation and to determine the type of structure so that appropriate damage curves could be assigned. GIS techniques allow the synthesis of this information with the available flood inundation information to estimate flood damages at each structure.

The determination of flood wave propagation requires additional post processing of already existing hydraulic simulations. This post processing establishes the movement of the flood front down the channel and computes times from a predetermined reference point. Estimates of bank full flows and a reference location and time were required to determine this propagation.

Communication tools are built around the base mapping already generated. The data developed in the risk assessment is portrayed on the base aerial photography that forms the foundation for the earlier displays. Additional information is added to clearly communicate the new information. Tabular data is provided to supplement the graphic displays. Together, these tools provide a comprehensive mechanism to communicate flood hazard and risk to the community.

4.0 DATA

Flood inundation maps form the basis for the risk assessment. Water surface elevations are predicted at all locations across the floodplain for the 10-, 25-, 50-, 100-, 200- and 500-year floods. This information is recorded by pixel and an elevation can be assigned to each structure within the floodplain.

Assessor's data is used as the basis for the assessed value of each property impacted by floods. This public record provides the economic foundation for estimating damages. It

also serves as the basis for the estimation of content values for residential structures. Based on published information, a content value is established for each structure as a function of structure type and assessed value.

Structure data tables are developed to summarize the assembled information for each structure. Much of this data was previously prepared and posted on the City's web site to communicate flood hazard data for properties identified to be within the floodplain. Information includes data related to the extent of flood hazard (i.e. location within a particular flood zone or within the conveyance or high hazard zone) and the computed water surface elevation adjacent to the property.

First floor and structure type information is added to the structure data table to facilitate the assignment of damage for various flood conditions. This information is critical in assessing the characteristics of the structure and the assignment of characteristic damages related to specific flood depths. These characteristic damages are based on curves published in FEMA's HAZUS guidelines. Herein, a relative percent damage to structures and contents is provided for each structure type. This, in combination with the depth of flooding, allows the estimation of damages associated with a particular flood event.

A comprehensive discussion of the data development and processing is included in Appendix A – South Boulder Creek HAZUS Assessment Using GIS. In that appendix, the processes used to filter and complete the data sets, how the various databases were merged and how information related to the determination of various hazards was developed is presented.

5.0 UNCERTAINTY

The assessment of risk is presented with an understanding that there is considerable uncertainty. As was identified in the hydraulic assessment, uncertainty permeates every element of the analysis. Hydrologic uncertainty was estimated to be +/- 20%. The topographic uncertainty was approximately 6 inches and the mapped floodplain elevation uncertainty was reported to be in that same range. In the hydraulic report, it was concluded that the upper range of uncertainty for the 100-year flood could be represented by the 500-year floodplain and the lower range of uncertainty by the 50-year flood.

Damage estimates also include uncertainly. While the damage curves represent the prevailing standard of practice, the assignment of value to a particular structure and the assignment of a representative damage curve do contain uncertainty. The assessed valuation of properties is probably within 10 to 15% given the rate of change of property values. A variation in the assignment of a representative damage curve is likely to change the damage associated with a particular depth of flooding by less than 10%. Therefore, in combination, these uncertainties are likely to be within 20 to 30%.

Since the hydrology is only +/- 20% and the depth uncertainty is the most substantial variant, it is reasonable to assume that computed damages may range by the difference in computed damage between the 50-year and 500-year floods. As will be reported later, these estimates range from $55M to $255M with the 100-year estimate being approximately $215M. This represents a range of uncertainty of -75%/+20%.

6.0 INUNDATION RISK

The inundation risk fundamentally defines the exposure of a particular area to flooding. The most common depiction of inundation risk is the 100-year floodplain map. This map defines the boundary of the area subject to flooding during the 100-year flood (that flood having a 1% probability of happening in any given year). This is the standard depiction for flood hazard, however much useful information regrading the severity of flood hazard can not be directly obtained from this data; it must be inferred.

6.1 USE OF INUNDATION MAPPING

A more useful measure of the potential hazard from inundation is an inundation map that depicts the depth of flooding across the floodplain.

Since the hazard associated with a flood is related to the depth of flooding adjacent to a structure, the inundation depth has greater application. For the South Boulder Creek study, depths of flooding were computed for each of the designated events. This information describes how floods impact a particular area and structure. The boundary of the inundated area can be described as the floodplain limits for the particular event in

question. While this data is not presented in precisely the same manner as the published 100-year floodplain, the information is substantially the same.

Inundation maps also are useful in establishing the frequency of exposure for a particular area or structure. The maps predict the extent of flooding for various events and show when areas may have more frequent exposure to floods or when flooding may be particularly deep in a given area. They also help define the threshold for which damages may occur at a particular structure.

One advantage of inundation mapping is that it has no socioeconomic bias. That is, no damages are assigned to the various levels of inundation. Rather, the only information provided is if a particular structure gets flooded during an event and to what depth the flooding is expected.

Inundation maps have been produced for the 10-, 25-, 50-, 100-, 200, and 500-year events. These maps depict the depth of flooding across the floodplain for each defined event. The 100-year Inundation Map was included in the FEMA submittal and was presented to the public at a number of previous public meetings. Inundation maps for the full range of events are posted on the project web site, on the City's ArcIMS site and are reproduced as Figures B-1 through B-6 in Appendix B – Flood Inundation Data.

The City and HAP recognized that large events other than design events can create a substantial flood hazard along South Boulder Creek or any other drainageway. For this reason, the study team was asked to produce inundation maps for several recorded events. Most notably, the 1969 South Boulder Creek flood was simulated and an inundation map produced. This event has a significant historic record and this record corroborates the mapping produced.

Figure B-7 in Appendix B – Flood Inundation Data shows the 1969 flood and depicts a rather significant flood hazard along both the main channel and the west valley. The flood of record on South Boulder Creek was recorded in 1938. The study team looked at this event very carefully and determined that the discharges and probable inundation are very similar to that of the 200-year flood as shown on Figure B-5 in Appendix B – Flood Inundation Data.

The study team also prepared inundation maps for two significant events that were recorded along the Front Range of Colorado, but not over South Boulder Creek. These two events, the 1976 Big Thompson flood and 1997 Ft. Collins flood, represent major storms that resulted in significant property damage and loss of life. The purpose of these inundation maps is to demonstrate that major recorded storms, should they fall over the South Boulder Creek watershed, can create a flood hazard significantly in excess of the regulatory flood. Inundation maps for the 1976 Big Thompson flood and the 1997 Ft. Collins flood are shown on Figures B-8 and B-9, respectively, of Appendix B – Flood Inundation Data.

The City also provides additional hazard data by presenting various zones of special hazard. The hydraulic analysis for this study produced the conveyance zone and high hazard zone maps. These special hazard zones depict areas that should be preserved for flood conveyance and where flows are particularly fast and/or deep. These maps were presented in the Hydraulic Summary Report and are reproduced here as Figures B-10 and B-11 of Appendix B – Flood Inundation Data.

6.2 SUBSEQUENT USES

Inundation maps have uses beyond merely depicting areas subject to flooding. These maps can be used to identify opportunities for simple mitigation such as structural flood protection. Often, structures that have shallow inundation are nominally impacted and can be protected with minor and cost effective modifications to the structure to prevent the entry of flood waters. Numerous references are available from the City, the Urban Drainage and Flood Control District or FEMA to help impacted citizens protect themselves from flood hazards that may be defined by inundation maps.

7.0 FLOOD DAMAGE RISK

Economic loss potential represents a broad range of hazards. For the purposes of South Boulder Creek, the losses are focused on flood damages. Other losses such as the disruption of normal activities, lost income or sales, alternative housing for displaced residents, etc. are beyond the scope of this effort and will not be addressed.

Flood damages are computed based on the depth of flooding at inundated structures and reported as the expected damages associated with that flooding. Assessed property values are used in combination with depth/damage curves defined for specific property types. The assessed values are obtained from public records accessed through the Assessor's Database. Each flooded structure is accessed via the address and an assessed value retrieved.

A HAZUS structure type is assigned based on information from the Assessor's Database or from physical observations in the field. The value of contents is established as a function of assessed value based on the HAZUS structure type definition. The HAZUS structure type defines a prescribed relationship between flood depth and damages as a percentage of structure and content value. Table C-1, Structure Data Table in Appendix C – Flood Damage Data presents the compiled information for all structures identified to be within the 500-year floodplain. This captures the entire envelope of structures that were evaluated during the damage estimation.

In combination, this information allows the determination of flood damages that can be expected at a particular structure during a particular flood. The process used is to determine the specific depth of flooding, determine the associated percentage of damages to structure and contents, and then compute the total damage to the individual structure. When summed for all structures and across the full spectrum of events, a clearer understanding of the economic consequence of flooding can be established.

Other damages, both direct and indirect, do occur as a consequence of flooding. Indirect damages such as lost income due to reduced sales, lost wages because people can't make it to work or cleanup costs during post flood activities were not included in this assessment. The focus of the effort was on tangible flood damage to structures.

Other direct damages such as damage to street or bridges can also be expected. Based on the hydraulic evaluations, most bridges along South Boulder Creek are not expected to incur significant damages. The duration of flooding is short and the extent of impact to these structures is limited. Roadway overtopping damage is another quantifiable source of damage. The Federal Highway Administration publication "*HEC 17 Design of*

Encroachments on Floodplains Using Risk Analysis" describes a process to quantify such damage. Their research shows that roadway overtopping damage is a function of depth and duration of overtopping. In an example they cite a roadway length of 1500 feet which is overtopped by1.5 feet for a duration of 40 hours. This overtopping resulted in a total damage estimate of less than $40,000. Given the limited depth and duration of roadway overtopping along South Boulder Creek, it was concluded these damages are not significant when compared to the damage associated with structure inundation. As such, these direct damages were not included in the damage estimates.

7.1 USE OF FLOOD DAMAGE RISK DETERMINATIONS

Flood damages are computed for each specific event using the data from the inundation mapping. Water surface elevations are compared to ground elevations at each structure and that depth used to determine the damage as a percentage of the overall structure value. Damages are assumed to occur only when the lowest ground elevation adjacent to the structure is below the water surface elevation. This threshold of damage is the same threshold as the one used to define whether a structure is in the floodplain.

The damage information is used for a number of damage risk assessments. First, the damage expected at a particular structure for each event is computed. This information is included in Table C-1 within Appendix C, Structure Data Table. This appendix can be viewed on the project website through the City's website at ci.boulder.co.us. The information presented in the table helps clarify those structures that are subject to damaging floods and the frequency and extent of that flooding. Graphically, the results of the structure damages for the 100-year flood are shown on Figure 1, 100-year Structure Damage. This map depicts the relative damage threat by showing those areas where the flood damage to structures is highest as red dots. Accumulations of red dots suggest areas where the extent of flood damage is highest for the 100-year flood. Note these areas are found along the main channel between Baseline Road and Arapahoe and through the commercial areas north of Arapahoe. Another block of red dots is found in the West Valley, also north of Baseline. Lesser damages are depicted as orange, yellow and green dots in declining magnitude of damage.

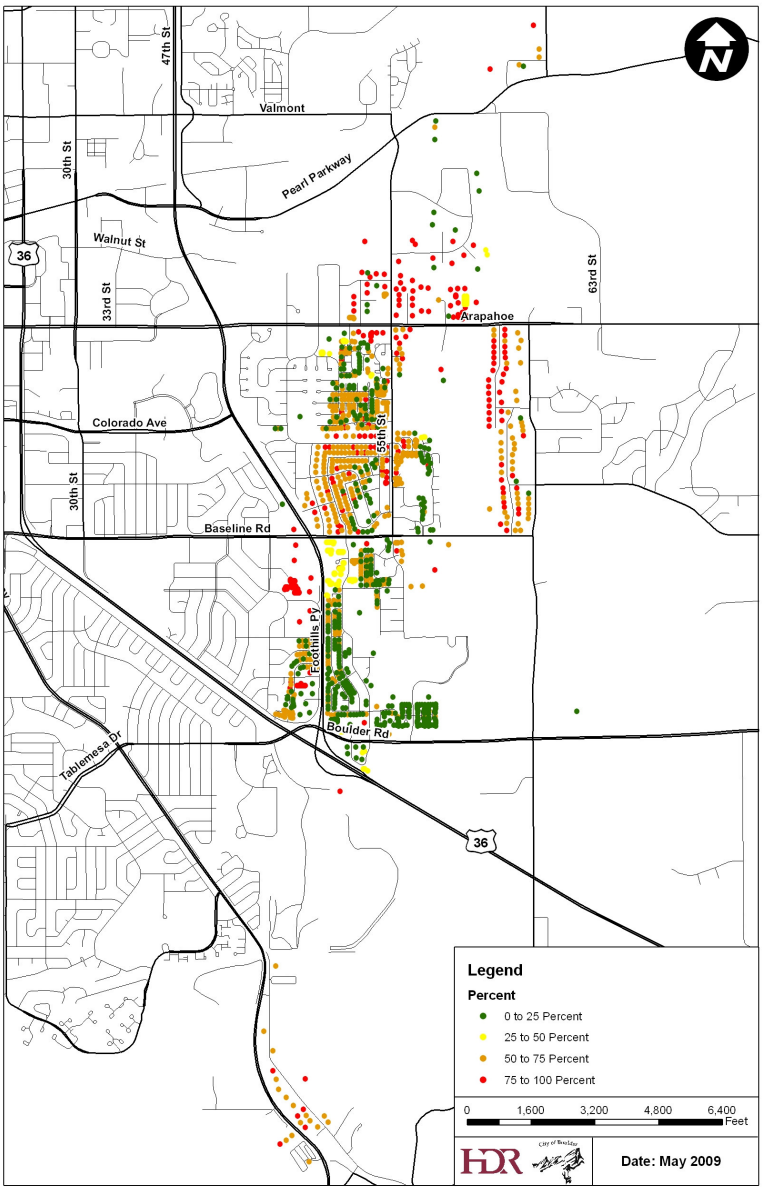

Figure 1. 100 Year Structure Damage

While very useful in determining the extent of damages to a particular structure, the results are skewed to high value properties. That is, a structure with the higher assessed value will experience greater damages for the same flooding conditions than a comparable but lower valued structure.

Using the individual structure data, total damage expected for each flood is computed. This is merely the summation of all the damage estimates for all the individual structures

for each event. This information is summarized in the Table C-1, Structure Data Table and is repeated herein as Table 1, Event Damage Summary.

The event specific damages can also be used to estimate the average annual damages by integrating over the entire range of probabilities. When combined, the total watershed average annual damages are estimated to be $8,700,000.

Table 1 Event Damage Summary

	10-Year	25-Year	50-Year	100-Year	200-Year	500-Year
Main Channel Contents Damage Cost	$3,500,000	$6,500,000	$7,300,000	$11,100,000	$12,700,000	$14,100,000
Main Channel Structure Damage Cost	$8,500,000	$14,200,000	$15,800,000	$24,700,000	$29,900,000	$31,900,000
West Valley Contents Damage Cost	$5,500,000	$7,800,000	$9,000,000	$62,400,000	$67,200,000	$69,800,000
West Valley Structure Damage Cost	$13,000,000	$18,700,000	$23,800,000	$119,300,000	$133,100,000	$138,000,000
Total Contents Damage Cost	$9,000,000	$14,200,000	$16,300,000	$73,600,000	$79,800,000	$83,900,000
Total Structure Damage Cost	$21,500,000	$32,900,000	$39,600,000	$144,000,000	$163,000,000	$169,800,000
Total Damage Cost	$30,500,000	$47,100,000	$55,900,000	$217,500,000	$242,800,000	$253,700,000

NOTE: Round the values reported in this table to the nearest $100,000.

As expected, the total damages increase as the probability of the floods decrease. This holds true for the total event damages and the individual structure damages. However, that information may not fully represent the complete flood damage risk. In many cases, the relative increment of flood damage may be small when flooding gets worse. A better measure of flood hazard is to develop a weighted flood risk. This merely recognizes that damage associated with frequent floods may have a higher impact than a large, but very infrequent damaging flood. To characterize the weighted flood risk, the information from Table C-1, Structure Data Table has been updated to incorporate weighted flood damages and is presented as Table C-2, Weighted Structure Damage Table in Appendix C – Flood Damage Data. This appendix can be viewed on the project website through the City's website at ci.boulder.co.us.. Graphically, this information can be used to determine at which event the greatest weighted damage occurs. Figure 2, Critical Damage Event shows the distribution of the critical damage event across the watershed.

The high number of green dots suggests that the highest risk of damaging flooding occurs in much of the watershed during the 10-year flood. The areas downstream of the US 36 where mainstem floods overflow into the west valley shows the critical damage event as the 100-year event. This suggests that overflows first cause significant damage during the 100-year flood.

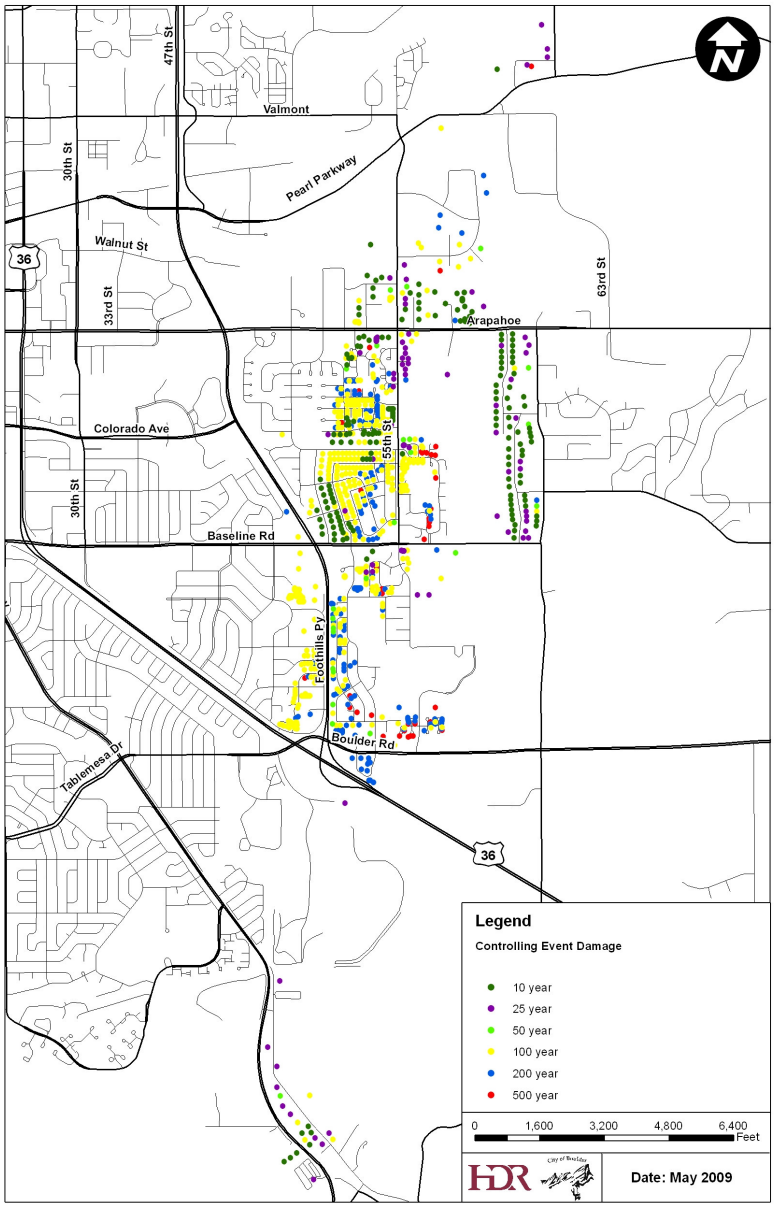

Figure 2. Critical Event Damage

7.2 SUBSEQUENT USES

Flood damage risk computations have significant value in future decision making. Understanding the damage at a specific structure, whether raw or weighted, helps to define the event for which mitigation should be considered. When the potential damage reduction offsets the cost of improvements, a sound economic justification exists. Certainly other considerations should be included when determining potential mitigation, but economic considerations need to be a part of any decision.

Similarly, average annual damages, whether within the entire watershed or at an individual structure, provide another measure of economic justification by comparing potential annual benefits against the amortized cost of improvements.

The graphic that displays the Critical Damage Event (Figure 2) is an important indicator of the relative threshold for significant damages. This graphic can help establish the appropriate design threshold for any mitigation measures and maximize the benefit of improvements. It may also be used to identify those areas where improvements have the most urgency.

8.0 BASIN RESPONSE TIME RISK

The basin response time is developed to define the flood threshold frontal wave propagation. That is, the time it takes for the front of damage producing floods to travel downstream from a predetermined reference point. For this study, the discharge of approximately 2,500 cfs has been determined to be the threshold for out of bank flooding. The basin response time determines how long after the Eldorado Springs gage has reached 2,500 cfs it takes for downstream reaches to experience floods in excess of 2,500 cfs.

The 500-year flood is the event that is used to predict travel times. The time when the discharge at Eldorado Springs reaches 2,500 cfs is set as time zero. Thereafter, the response time risk is reported as the time from time zero until flows reach 2,500 cfs at select locations or at set time intervals downstream. Figure 3, Basin Response Time depicts the advancement of damage producing flows in the watershed at defined time intervals. The lines on this figure predict the available warning in the lower watershed. This basin response time to select locations is depicted in tabular form in Table 2, Basin Response Time.

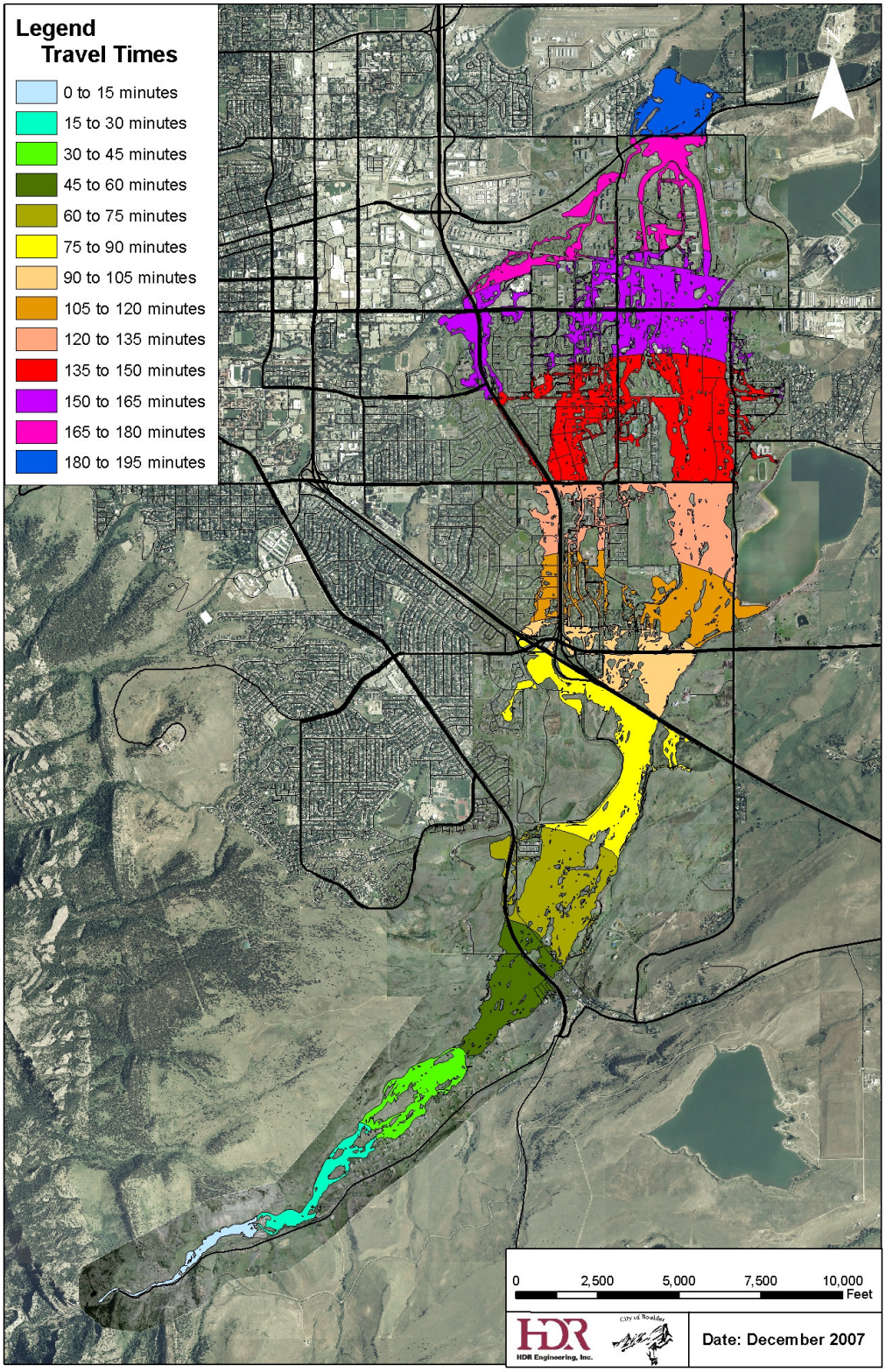
Legend
Travel Times
0 to 15 minutes
15 to 30 minutes
30 to 45 minutes
45 to 60 minutes
60 to 75 minutes
75 to 90 minutes
90 to 105 minutes
105 to 120 minutes
120 to 135 minutes
135 to 150 minutes
150 to 165 minutes
165 to 180 minutes
180 to 195 minutes
0
2,500
5,000
7,500
10,000
Feet
HDR
HDR Engineering, Inc.
City of Boulder
Date: December 2007

Figure 3. Basin Response Times

Table 2. Basin Response Times

Location	Clock Time	Travel Time
Eldorado	20:00	0:00
SH-93	20:50	0:50
US-36	21:30	1:30
Baseline Road	22:15	2:15
Confluence	23:20	3:20

Basin response is also shown through animations. These animations show the advancement of flooding and enable the viewer to better understand how water moves through the system and across the floodplain.

Several different events (50-, 100-, 200-, 500-year floods as well as the 1969 South Boulder Creek flood and the 1976 Big Thompson and the 1997 Ft. Collins floods) are simulated and can be viewed on the project website through the City's website at ci.boulder.co.us.

8.1 USE OF BASIN RESPONSE TIME INFORMATION

The basin response time graphic shown in Figure 3 is invaluable in helping emergency responders determine how to create and communicate warning messages. Using actual recorded gage data to set time zero assures that conditions are already very near flood stage. The use of the 500-year flood to predict flood wave propagation speed is somewhat conservative but defines the shortest available lead times. With this information, emergency responders can offer credible and timely warnings and communicate appropriate actions.

Emergency responders can also use this information to help mobilize staff and equipment to particularly critical areas prior to the onset of catastrophic flooding. This staff may be able to help implement flood preparedness actions and minimize the threat to citizens.

The animations provide a powerful presentation of the flood hazard. The clarity of the movement of the flood wave for the various events is useful in communicating the source of floods and in understanding when and how areas might be subject to risk.

8.2 SUBSEQUENT USES

The basin response time information can be used to support refinement of flood warning response planning. As planning exercises are conducted and the flood warning systems along South Boulder Creek better understood, refinements can be made based on the available response times. For example, if the reported time for the flood producing flows to travel downstream is too quick to allow adequate implementation of the response, the threshold discharge at Eldorado Springs can be adjusted. This additional time may allow better implementation and subsequently a more effective protection for the public.

The basin response information can also be used to communicate hazards to public. The animations have already proven to be helpful in displaying the flood propagation through the watershed.

However, the animations may be particularly helpful in defining escape routes if evacuations are needed or in identifying areas within neighborhoods that have a lower flood hazard.

9.0 ENVIRONMENTAL IMPACT RISK

The environmental risk is intended to describe some of the threats to the natural environment. These are particularly hard to quantify. For the purpose of South Boulder Creek, some indicator conditions have been identified that may predict broader impacts to the natural environment. Velocity and depth are indicators of environmental hazard. These parameters were previously identified as part of the High Hazard Area determination and therefore only required some alternative sorting to establish environmental risk factors.

Erosion is one of the greatest flood induced threats to the natural environment. As such, efforts have been taken to determine the erosion hazard impacts to stream banks and overbank areas. The site specific evaluation of these threats was beyond the project scope, however, it is possible to determine the velocity across the floodplain and assign a relative hazard to areas within the floodplain. This hazard is reported as a range of velocities for the 100-year event.

Four ranges are presented in Figure 4, 100-Year Floodplain Velocity Distribution. These velocities are determined by identifying the maximum velocity during the 100-year flood for all locations along the channel and across the 2D grid.

In general, low velocity flows less than 3 fps have little erosion potential and represent limited risk. Velocities between 3 and 5 fps may have some erosion potential but only over unprotected, non-cohesive soils. Areas subject to velocities between 5 and 9 fps are likely to experience erosion unless the area is stabilized, however, lesser events may have lower velocities and a less extreme erosion hazard. Areas subject to velocities above 9 fps are almost certain to be vulnerable to erosion.

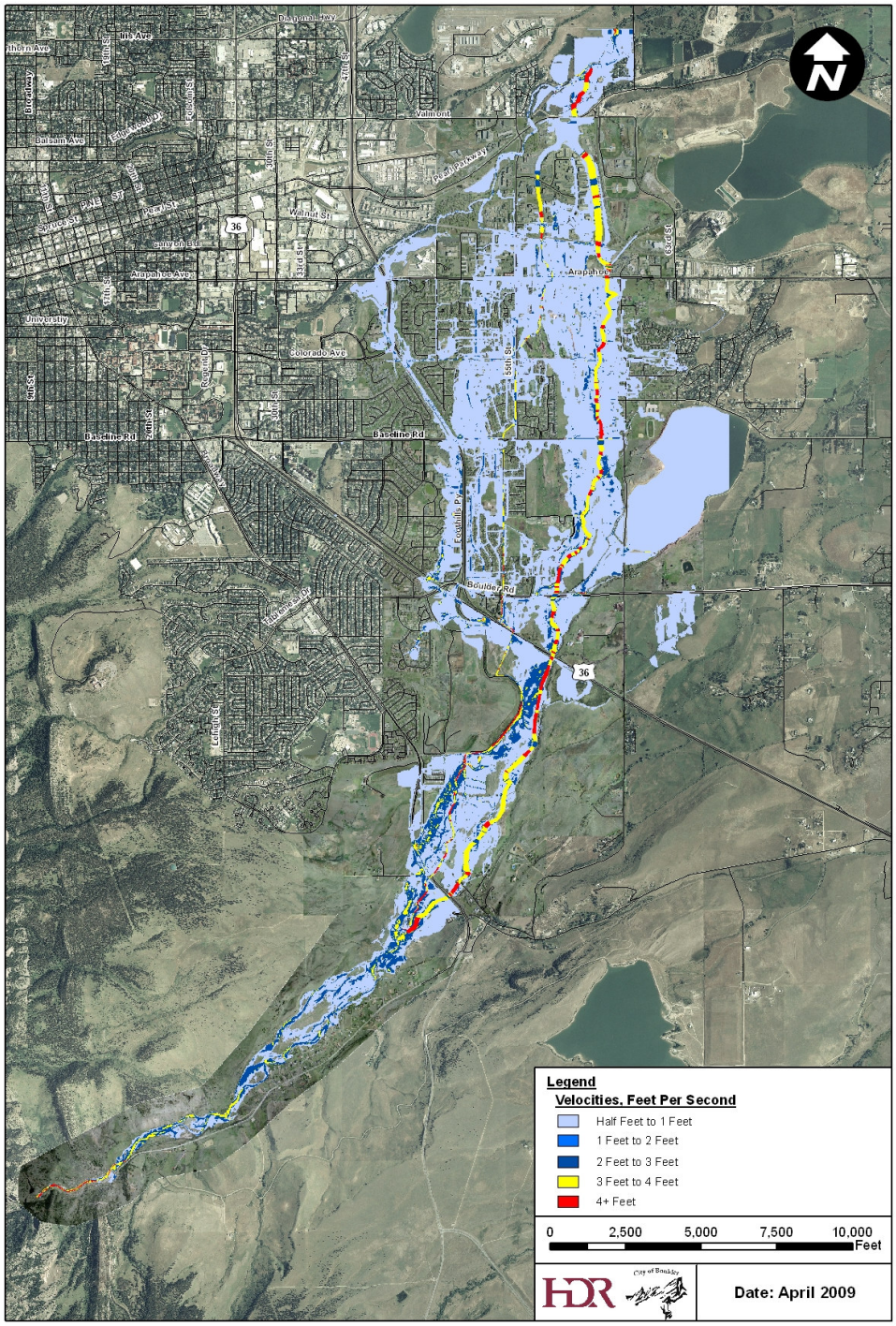

Figure 4. 100-Year Floodplain Velocity Distribution

A second measure of environmental risk is depth of flow. Depth increases stream power and therefore the ability to erode and transport sediments. In many cases, extreme depth

may also endanger riparian vegetation. Depth hazard is presented as a range of values in Figure 5, 100-Year Floodplain Depth Distribution. Depths of flooding are determined by identifying the maximum depth at every pixel in the 2D grid and along the channel cross sections of the 1D model.

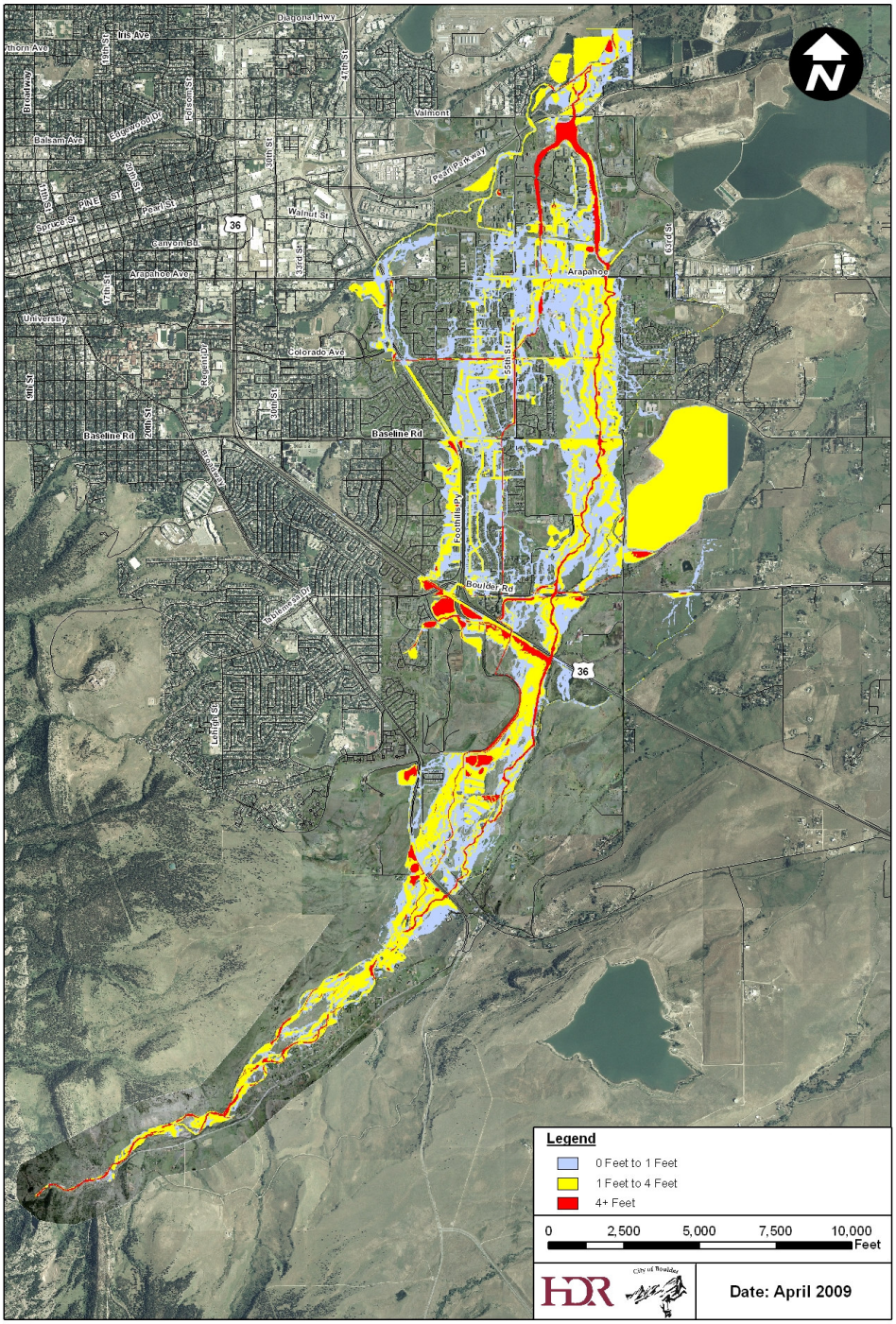

Figure 5. 100 Year Floodplain Depth Distribution

Depths less than 0.5 feet have little long term impact and are likely to be transient. Depths between 0.5' and 1.0' also represent relatively low hazard and are likely to have few significant environmental impacts.

Flow at depths between 1.0' and 4.0' can cause damage to habitat areas and poses a risk to the public. Flow at depths greater than 4.0' is likely to cause significant damage anywhere except in the main channel conveyance area. Vegetation may be uprooted and debris may impact future function or recovery.

9.1 USE OF ENVIRONMENTAL RISK DETERMINATIONS

Environmental risk delineation helps to define those areas of highest vulnerability. This information can be used to identify target areas for monitoring, restoration or protection. By understanding the potential risk, appropriate measures can be employed.

This determination does not reflect any specific environmental feature. As such, it is necessary to first identify those features of interest and use the information presented herein to help understand the risk. The synthesis of feature and risk is not part of this assessment.

9.2 SUBSEQUENT USES

It is possible to use this information in combination with mapping of areas of high environmental value to identify areas for further study. Certainly, the velocity and depth information presented herein can be used to identify those areas where channel instabilities are most likely. These are areas of further study or immediate repair if conditions warrant.

The information herein may also be used to define areas of future setback. Both high velocity and depth are natural phenomena that may be unrelated to any actions of man. As such, it may be preferred to use the information to define setbacks or to impose other zoning or development restrictions that allow natural processes to occur in a way that pose no increased threat to the public. Over time, the stream will reach equilibrium and the high velocities and depths may be fully mitigated without intervention.

10.0 SUMMARY

Risks associated with flooding along South Boulder Creek are inevitable. Many of these risks are associated with inundation and are unavoidable but their impacts can be mitigated. Nevertheless, appropriate understanding of these risks can avert major consequences through proper planning, effective warnings and selective protections.

The information of this section is the foundation for understanding how to most effectively embark on future mitigation efforts. Knowing where water will be under certain conditions, how deep and fast it flows, and where flood flow originated is the basis for development of alternative mitigation measures. This information also allows the City to look at future administration and regulation of the floodplain by better understanding the highest vulnerabilities and addressing them accordingly.

APPENDIX A - SOUTH BOULDER CREEK HAZUS ASSESSMENT USING GIS

SOUTH BOULDER CREEK HAZUS ASSESSMENT USING GIS

The City of Boulder provided two GIS shapefile layers to aid in the HAZUS Assessment. One shapefile layer consisted of the structures. The other shapefile consisted of the land parcels. The parcel's attribute table included the addresses, the assessed value of the structures on the parcel, the owner's name along with various zoning types and other information. The structure's attributes table did not have any data associated with it. A relationship was developed between these GIS coverages to allow the structures in the structure shapefile to be indexed to an assessed value, structure type and other information in the land parcel shapefile. This relationship was created by the use of a primary key field which was labeled BLDGNUM. This field correlated the structures layer to the parcels layer. Another field labeled BuildingID was created to identify each structure since multiple structures could reside on one parcel.

Certain information was needed to perform a HAZUS Assessment such as the structure's first floor height from the lowest ground elevation, the type of structure (ranch, split-level, etc), and whether or not the structure had a basement. This data was collected by visual inspection of the approximately 600 blocks that fell within the 500 year X Zone floodplain. All of this data was input into the structure's attribute table.

This MIKE FLOOD inundation raster outputs for the 10-, 25-, 50-, 100-, 200- and 500-yr floodplains were used to determine the flooding heights at each structure. These floodplain inundation rasters showed the depth of the flooding and had to be changed to show the height of the water. This was performed by adding the inundation rasters to the 1 meter Digital Elevation Model (DEM) raster using Raster Calculator in Spatial Analyst. The final output was a raster showing the water surface elevation predicted for each flood recurrence probability.

The next step determined the flood heights on the structures. This was performed by the Spatial Analyst - Zonal Statistics tool in ArcGIS. This tool allowed for the maximum height of the water to be quantified for each structure that intersected the flood height rasters. The Zonal Statistics tool was also used to determine the lowest elevation of the ground to each structure. The first floor heights from the ground, which were approximated during the visual inspection, were added to this lowest ground elevation which produced the first floor elevations. The HAZUS flood height of the water was then determined by subtracting the first floor elevations from the flood height elevations on the structures for each of the flooding events. Figure A-1 illustrates how these elevations affected the structure.

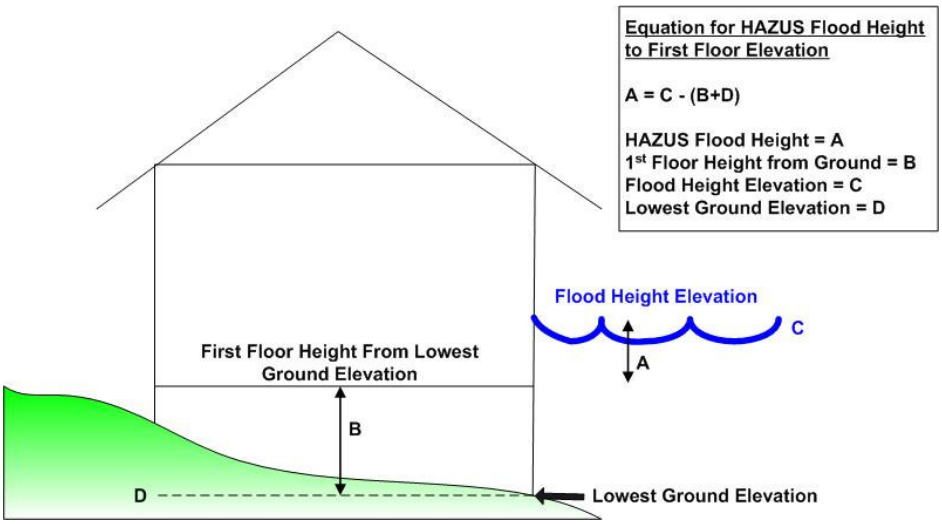

Figure A-1. Structure profile.

A table was created from the structures and parcels attribute tables and placed into an excel report. The HAZUS curves were then assigned to the various structure types to determine a cost per height of water above the first floor elevations. These curves represent characteristic damage versus depth relationships for various structure types. Assignments were made based on the visual field inspections conducted earlier. Residential structure curves were defined based on specific observed conditions at each structure. Commercial and industrial structures were

grouped and characteristic but general curves were assigned. These curves reflect typical damage relationships for the range of commercial buildings found in the watershed.

Similar curves were used to reflect content damage within the various structures. Basements were also taken into consideration as well. The final output was the estimated costs for each flooding event broken down into structure damage and contents damage.

The average annual damage was also calculated by summing the area under the damage vs. probability curve.

APPENDIX B - FLOOD INUNDATION DATA

Floodplain Inundation 10yr TStorm

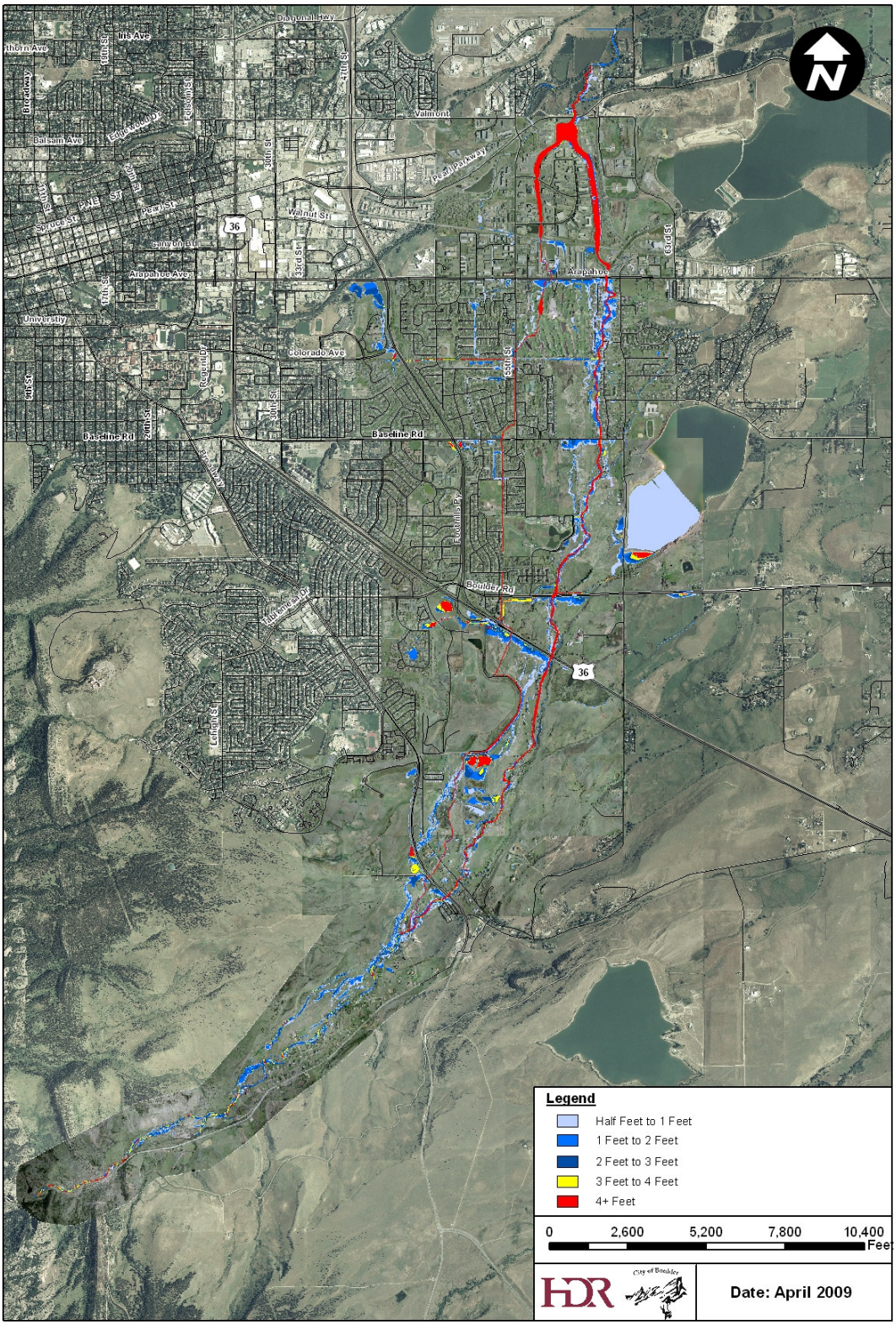

Figure B-1. 10-Year Inundation

Floodplain Inundation 25yr TStorm

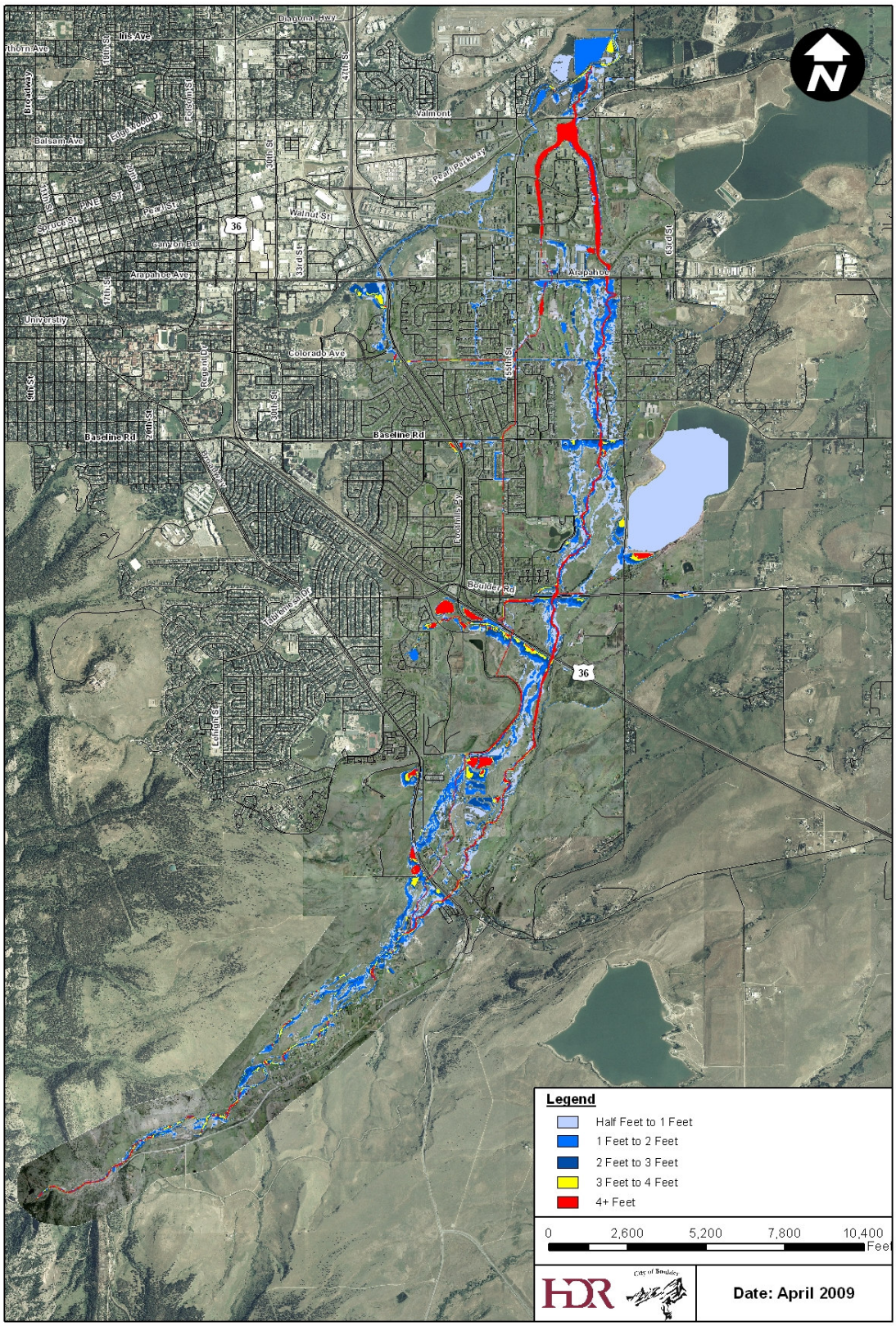

Figure B-2. 25-Year Inundation

Floodplain Inundation 50yr TStorm

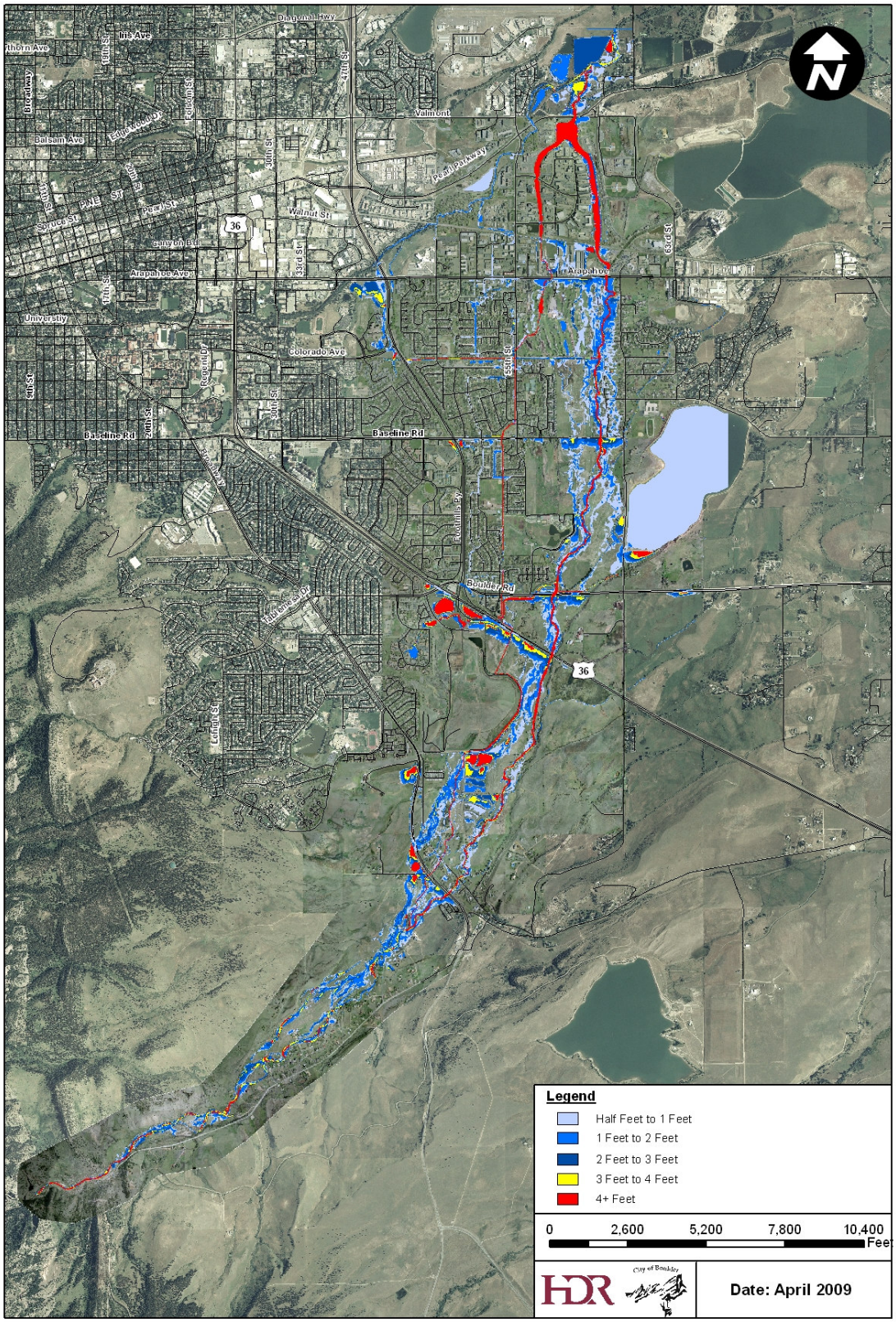

Figure B-3. 50-Year Inundation

Floodplain Inundation 100yr TStorm - CU Berm

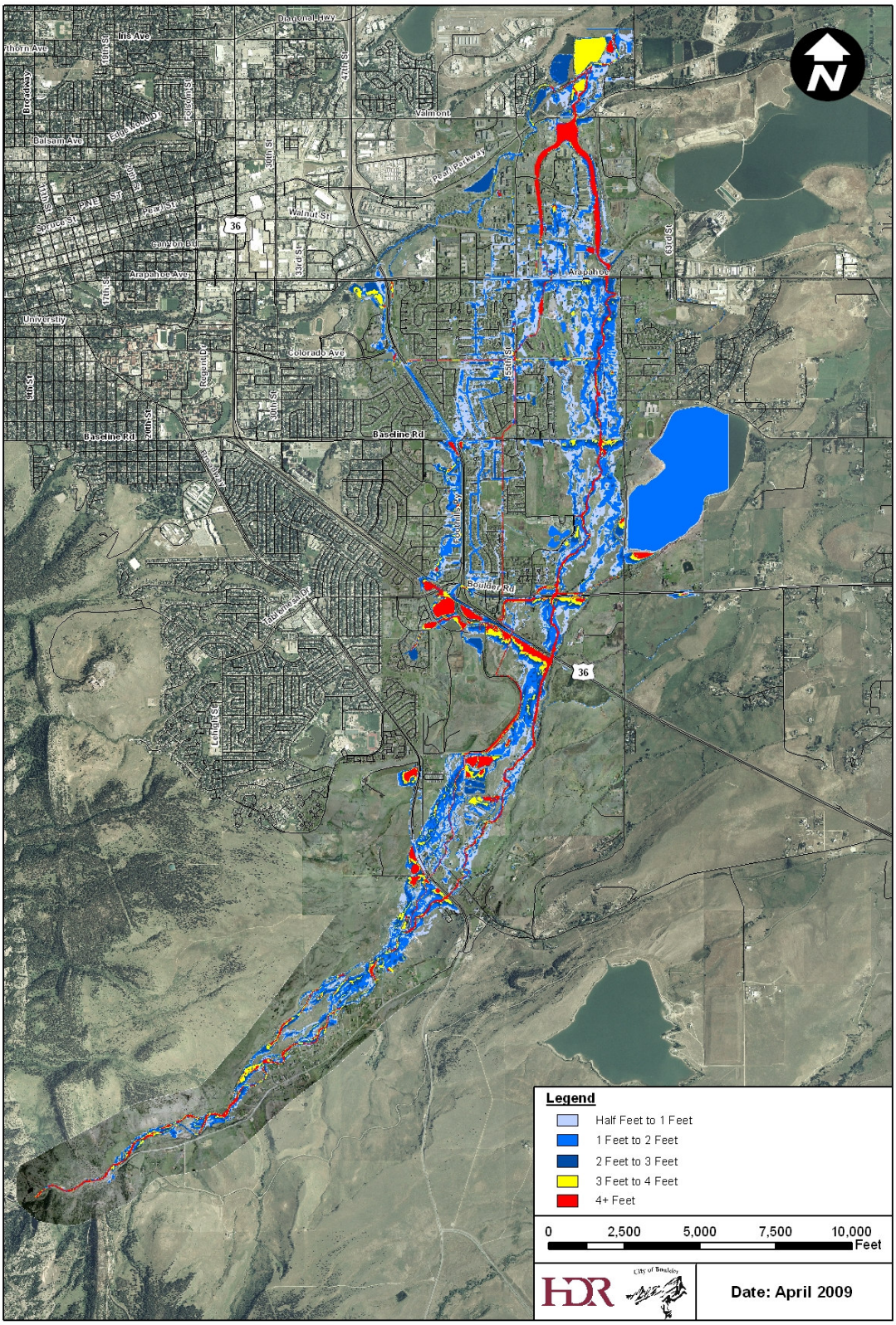

Figure B-4. 100-Year Inundation

Floodplain Inundation 200yr

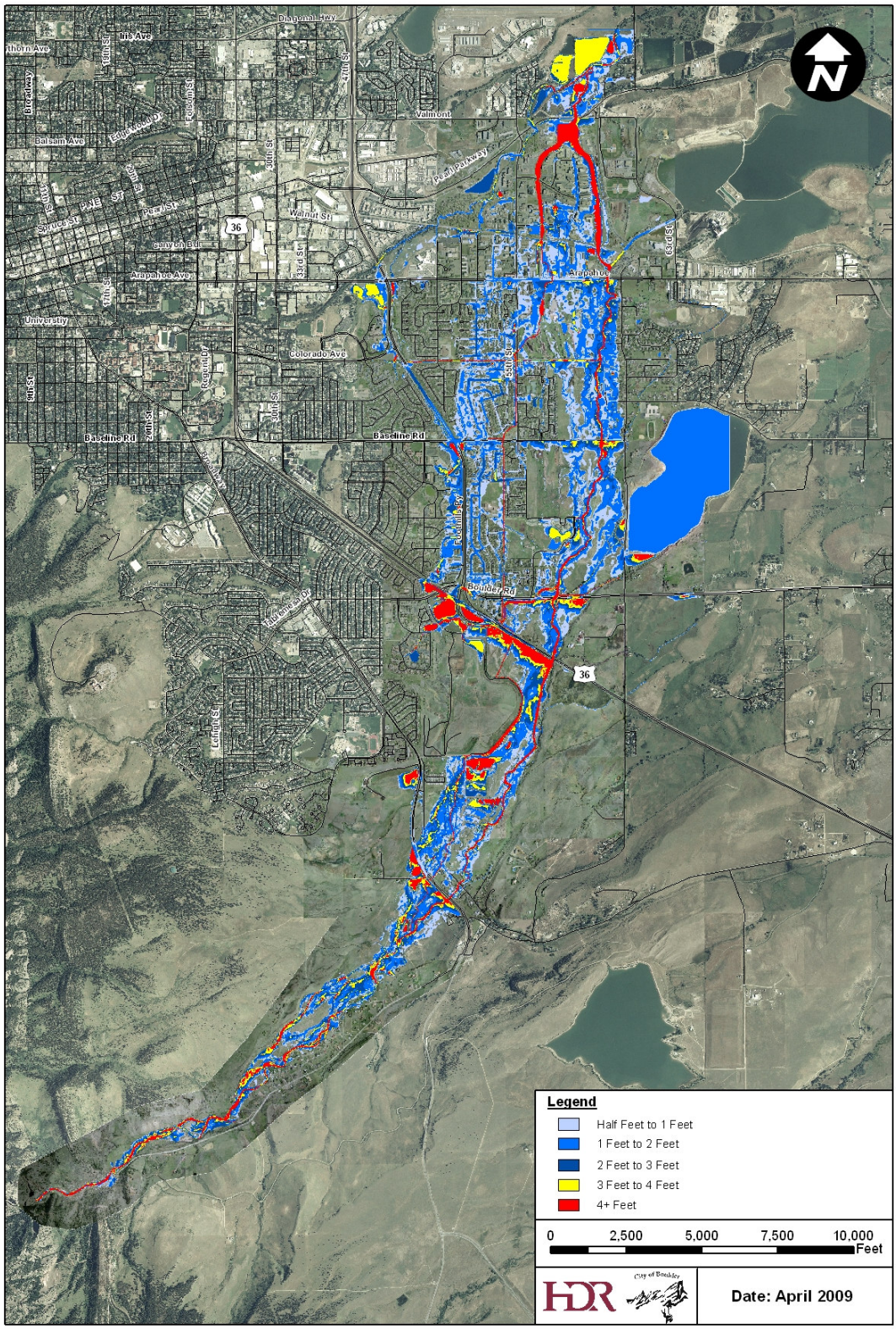

Figure B-5. 200-Year Inundation

Floodplain Inundation 500yr TStorm - CU Berm

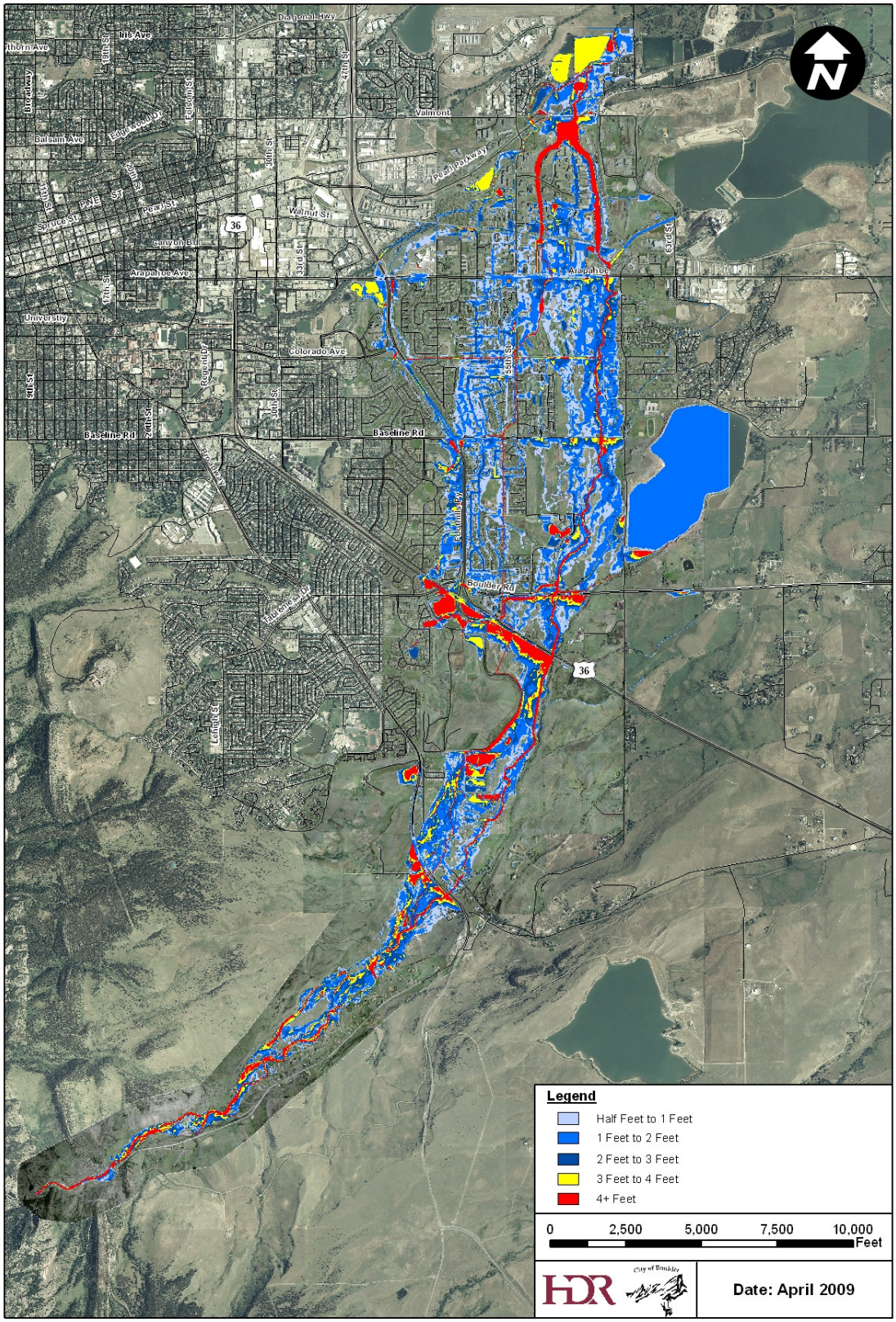

Figure B-6. 500-Year Inundation

1969 South Boulder Creek Inundation

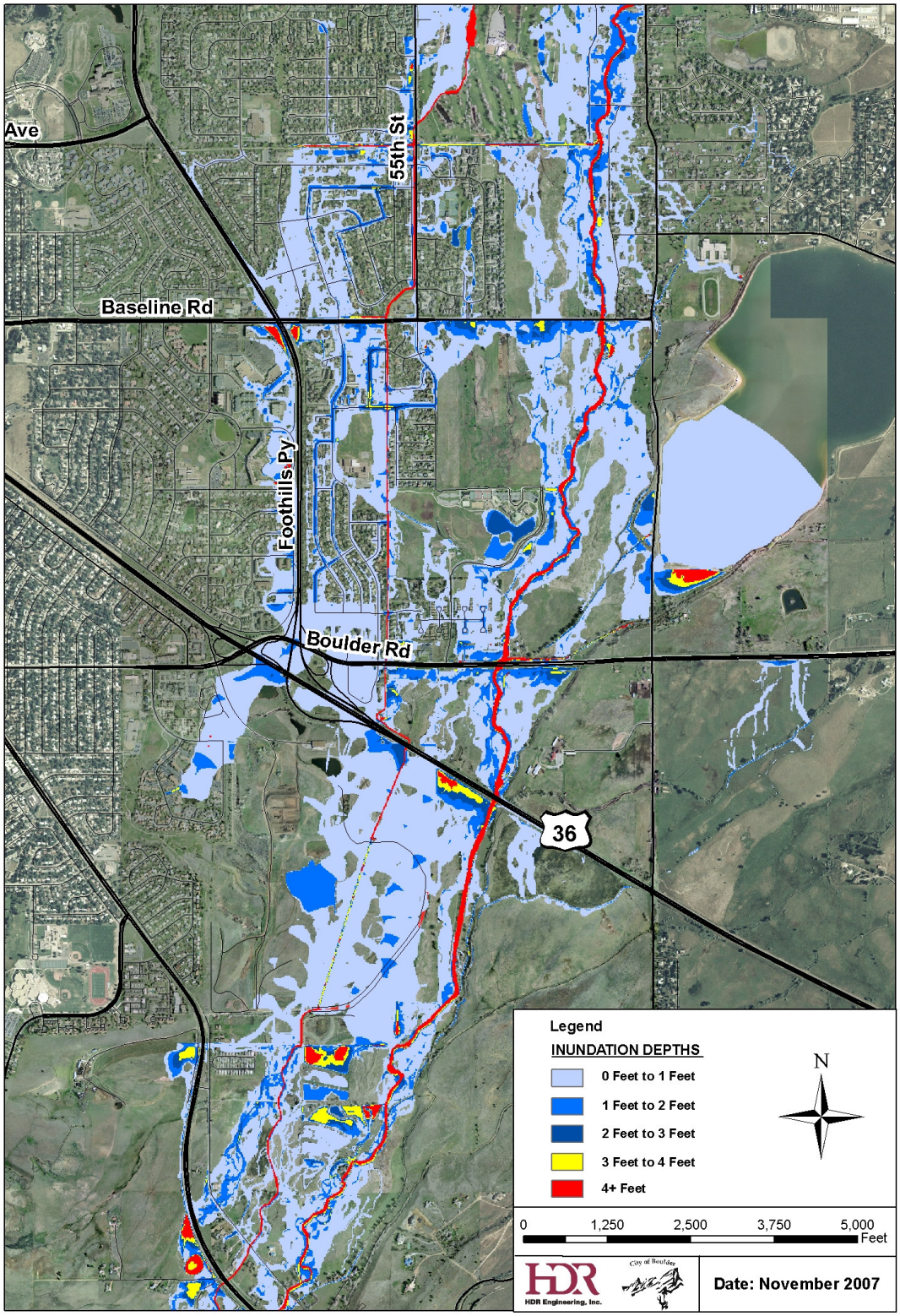

Figure B-7. 1969 Storm Inundation

1997 Fort Collins Storm Inundation

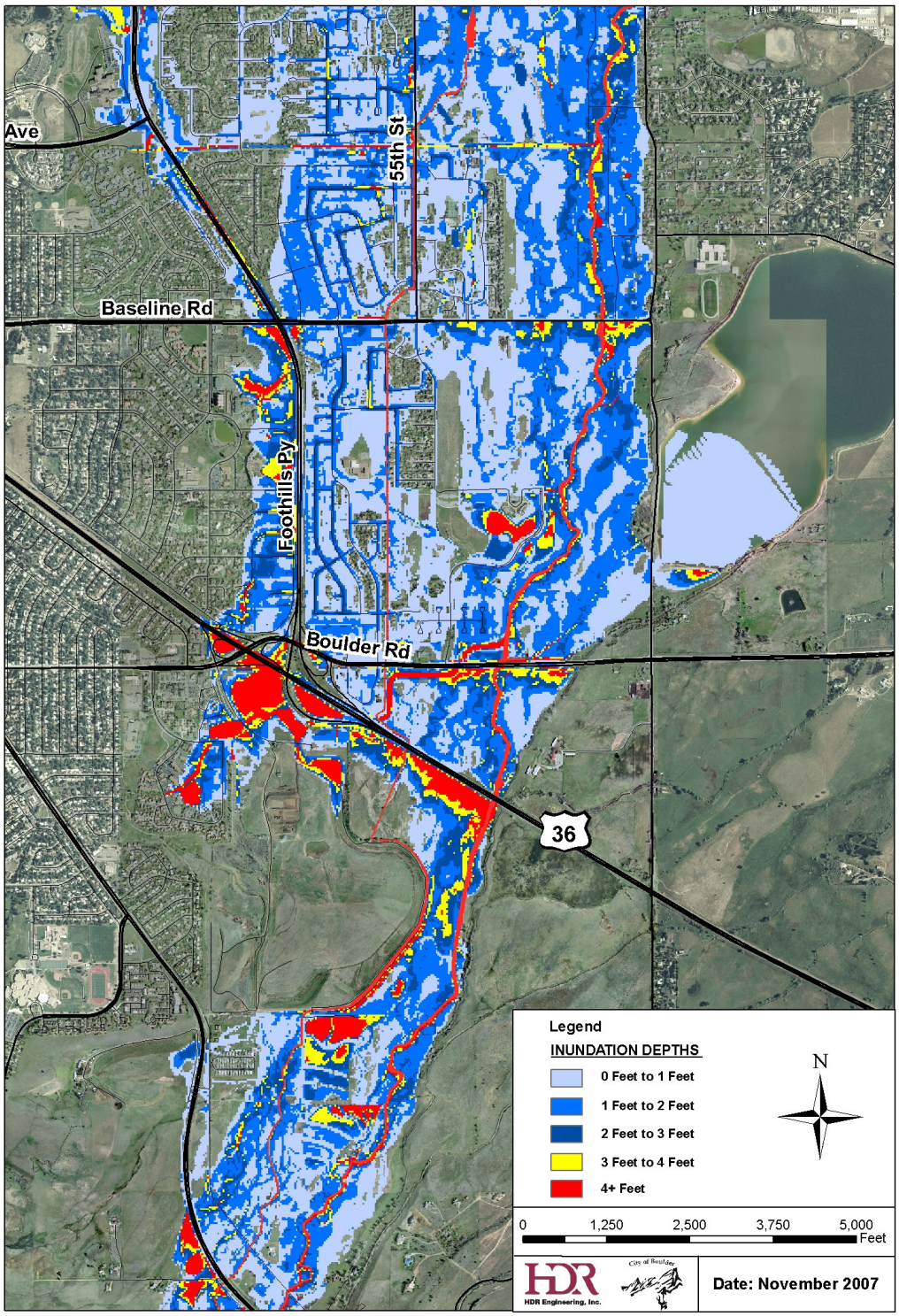

Figure B-8. 1997 Storm

1976 Big Thompson Storm Inundation

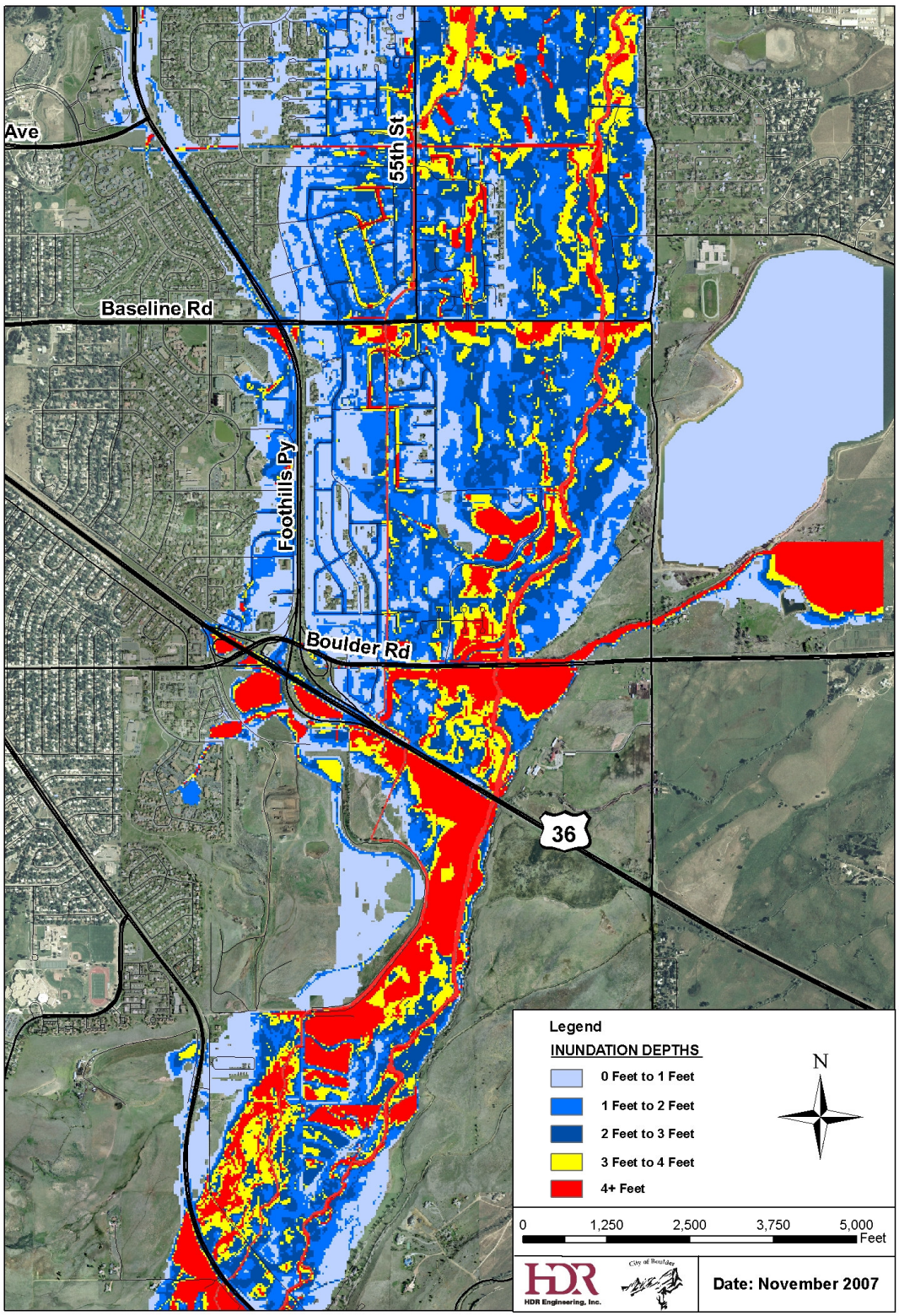

Figure B-9. 1976 Storm Inundation

South Boulder Creek Conveyance Zone

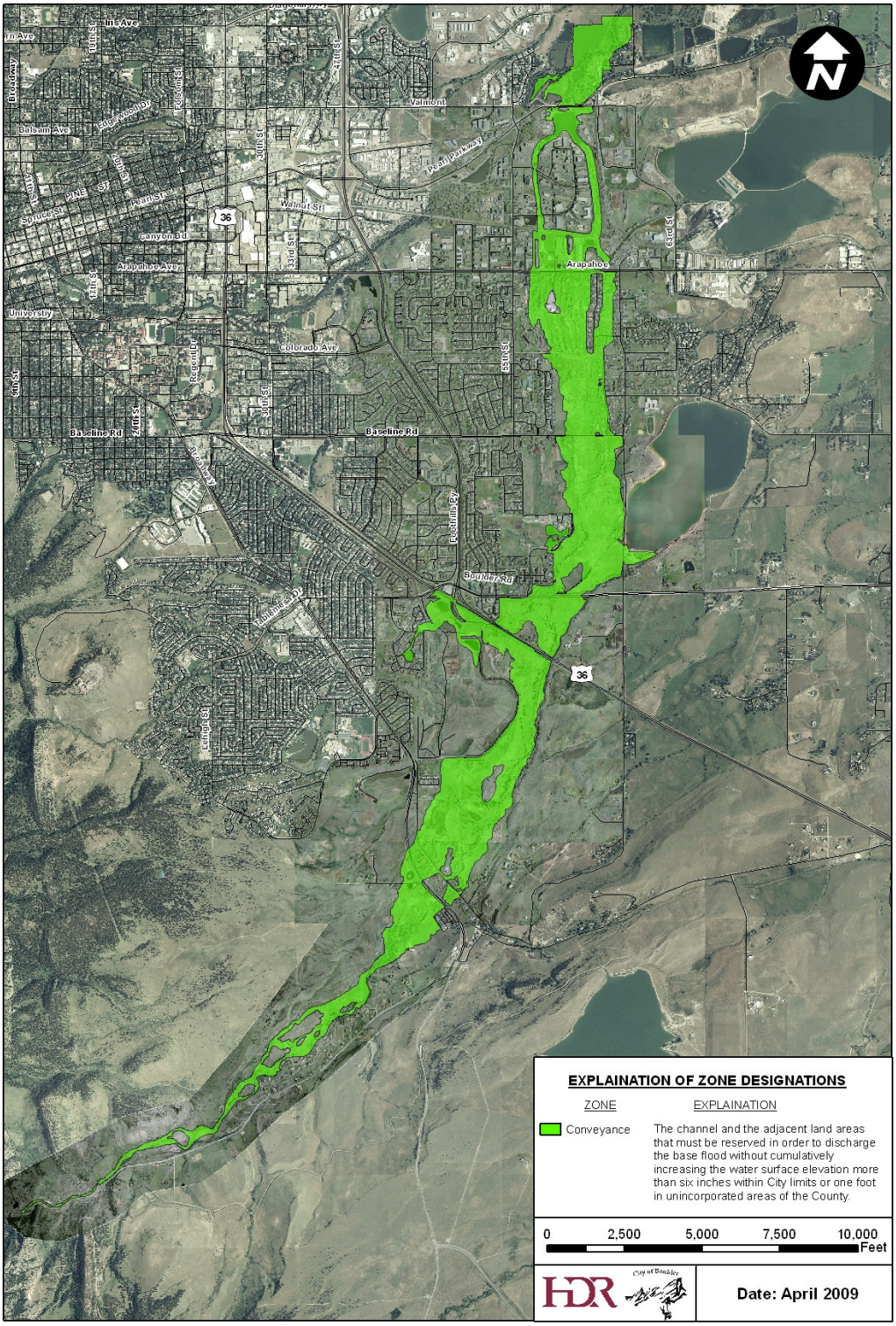

Figure B-10. Conveyance Zone

South Boulder Creek High Hazard Zone

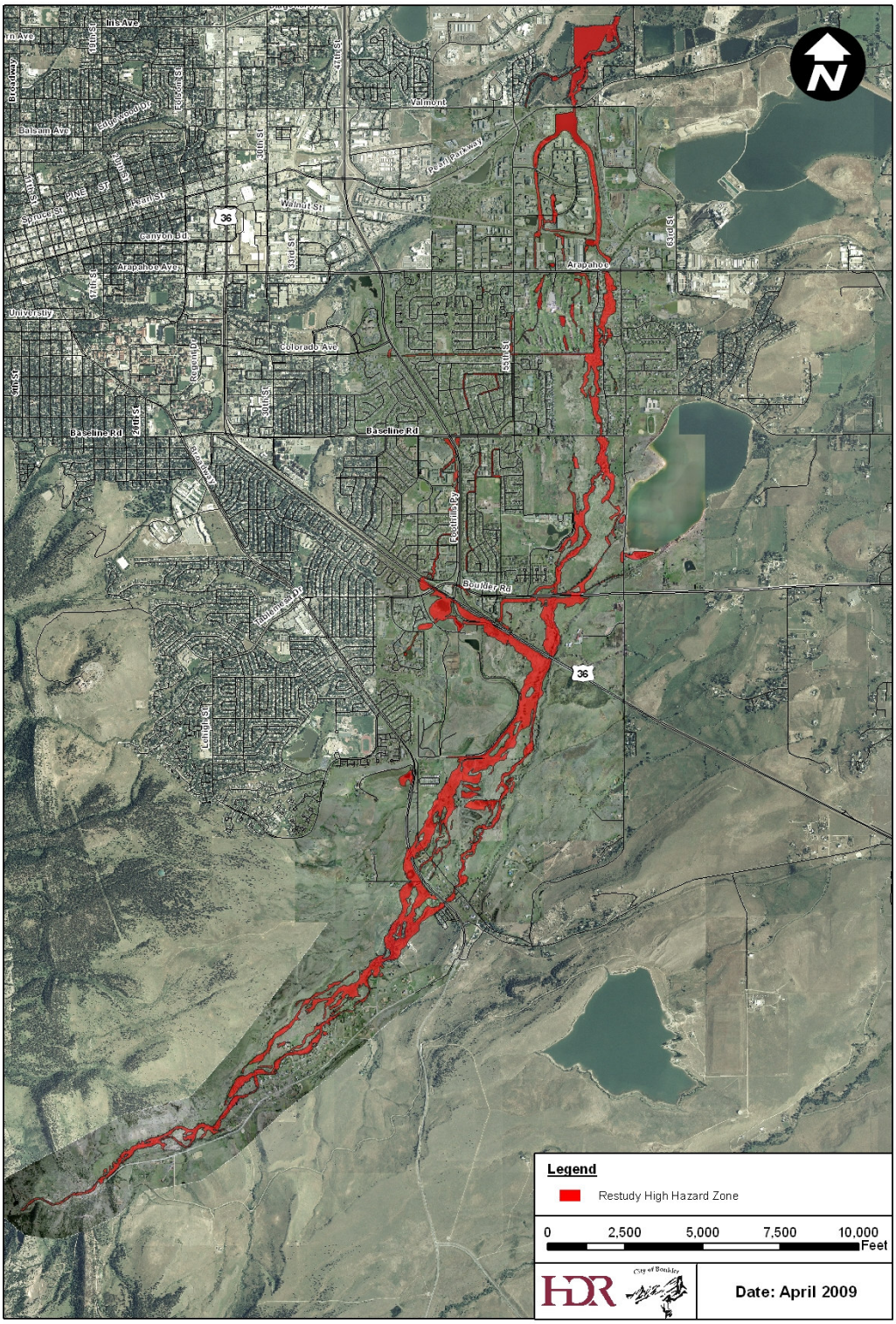

Figure B-11. High Hazard Zone