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USING GIS TO EVALUATE THE EFFECTS OF FLOOD RISK ON RESIDENTIAL PROPERTY VALUES

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1. Introduction

Annually, flooding causes more property damage in the United States than any other type of natural disaster. One of the consequences of continued urbanization is the tendency for floodplains to expand, increasing flood risks in the areas around urban streams and rivers. Hedonic modeling techniques can be used to estimate the relationship between residential housing prices and flood risks. One weakness of hedonic modeling has been incomplete controls for locational characteristics influencing a given property. In addition, relatively primitive assumptions have been employed in modeling flood risk exposures.

We use GIS tools to provide more accurate measures of flood risks, and a more thorough accounting of the locational features in the neighborhood. This has important policy implications. Once a complete hedonic model is developed, the reduction in property value attributed to an increase in flood risks can, under certain circumstances, be interpreted as the household’s willingness to pay for the reduction of flood risk. Willingness to pay estimates can in turn be used to guide policymakers as they assess community-wide benefits from flood control projects.

2. Hedonic Theory and Literature

The hedonic price model used in this study has its roots in the works of Lancaster (1966) and Rosen (1974). It is based on the premise that individuals can choose consumption levels of local public goods such as environmental quality through their residential location choice. The model views the price of individual houses as dependent on a bundle of housing characteristics. These characteristics include those related to the structure (e.g., lot size, number of bathrooms, etc.); the neighborhood (e.g., average commute time, median household income, etc.); the environment (e.g.,variables related to flood risk); and fiscal factors (e.g., property tax rates).

There are several underlying assumptions in this model. The model assumes that the study area is a single market for housing services. It also assumes that all buyers and sellers have perfect information on the alternatives that exist and that the housing market is in equilibrium. This last assumption means that all households have made their utility maximizing choice in terms of residential location given the prices of alternatives, all of which just clear the market. The relationship outlined here can be linear only when repackaging of the house is possible, and in general, this is not the case. When an individual makes a residential location decision, they are accepting the entire bundle of housing characteristics. It is not possible to trade a house with two full baths upstairs for the exact same house with one full bath upstairs and one downstairs. Thus, the function is nonlinear.

Given the previous assumptions, the market clearing price of the house is treated as parametric and can be represented as p(Z), where $Z = z_{1,} z_{2, \ldots ,} z_n$ is a vector of n structural, neighborhood, and environmental characteristics. The housing market implicitly reveals the hedonic function, p(Z), which relates prices and characteristics. This price functioin p(Z) is a reduced form equation representing both supply and demand influences in the housing market. The implicit price of attribute n is given by the partial derivative of p(z) with respect to attribute n, or $p_n(z) = \partial p/\partial z_n$. That is to say, the partial derivative with respect to any of the aforementioned characteristics in the function can be interpreted as a marginal implicit price of that characteristic. This marginal implicit price is the additional amount that must be paid by any household to move to a bundle of housing services with a higher level of that characteristic. For example, the coefficient on the number of rooms in a home may be interpreted as the price that must be paid by the household to move from a house with eight total rooms to the same house with nine total rooms, all else constant. Since the function for housing is nonlinear, the marginal implicit price depends on the quantity of the characteristic being purchased.

Several hedonic studies specifically address the issue of flooding including the effect of floodplain regulations on residential property values (Schaefer 1990), the impact of subsidized and nonsubsidized flood insurance on property values (Shilling et al., 1987), and the influence of flood risk on property values (Barnard 1978; Park and Miller 1982; Thompson & Stoevener 1983; Donnelly 1989; Speyrer and Ragas 1991; Shabman and Stephenson 1996). For the most part, the results from these studies indicate that location in a floodplain, or proxies for flood risk, negatively impacts residential property values. One study examined a major flood event (Babcock and Mitchell 1980); however, this was done by a comparison of prices before and after the event, and thus was vulnerable to bias due to omitted factors in the analysis. None of these studies measure flood risks directly, nor do they investigate the impact of a specific flooding event in an hedonic framework.

3. Definition of Flood Risks

A flood is defined for the purpose of this paper as a stream discharge greater than the capacity flow of the channel. This is obviously a very simplistic definition. For example, Williams (1978) presented 11 definitions of the channel bankfull flow, from which the flow that reaches the valley active floodplain is the one accepted by most river morphologists. A flood of certain magnitude occurs or is exceeded with a certain frequency. The most common flow used for delineation of floodplain is the flow with the recurrence interval T_r = 100 years, i.e. the risk of flooding is $r = 1 / T_r = 1/100 = 0.01$.

The delineation of the floodplain for a flow of given frequency is a tedious task. Such tasks usually involve the development of a complex hydrologic/hydraulic model. Once calibrated, the model can be used to simulate a wide range of flows and the flow-elevation relationship can be obtained. Hydraulic models can be combined with GIS systems to delineate a floodplain for any recurrence interval (e.g., McLin, 1993, Correia et al., 1998). However, this requires a considerable amount of data and substantial effort. Thus, a simplifying alternative has been proposed in this study.

The extent of 100-year floodplain, often used for engineering and flood insurance purposes, is delineated by Federal Emergency Management Agency (FEMA). The flood risk varies within the floodplain and decreases with increased distance from the channel. The properties located within the 100 years floodplain are under different risks of flooding and hence there is a need to express a flood risk relation in the urban floodplain.

A schematic representation of the following concept is shown in Figure 1. The channel can contain a flow with a certain recurrence interval. This flow is called a capacity flow, or bankfull flow. As one moves away from the river's edge, the probability of flooding decreases, and at some point at a distance x from the river the recurrence interval of flooding becomes 100 years, i.e., the risk of flooding is $r(x) = 0.01$. This is the extent of the 100-year floodplain that is useful for many engineering and flood insurance purposes.

Channels of natural streams are in an equilibrium with the flow. Leopold, Wolman, and Miller (1995) document that channels of rivers in eastern and Midwestern US have a channel capacity that can contain a flow that has an approximate recurrence interval of about 1 ½ years. For example, if the smallest flow that leaves the channel is about a 2-year flow before urbanization, then the risk of flooding at the edge of the river is r(0) = 1 / 2 = 0.5.

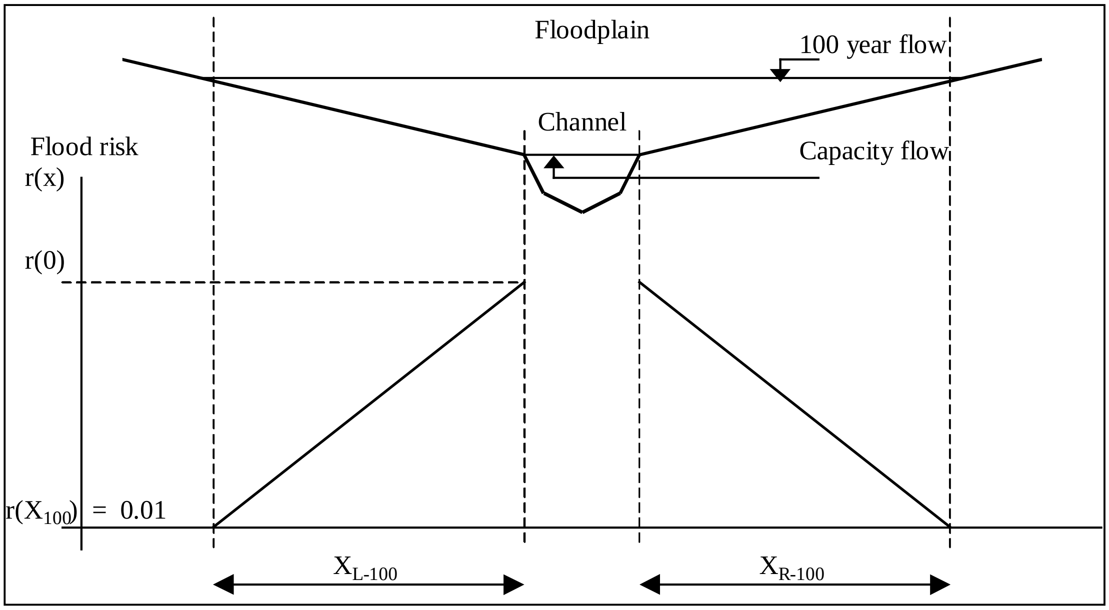

Figure 1: Concept of flood risk

The scale of the risk function *r*(*x*) should be logarithmic, i.e., a zero risk of flooding is expected to occur at an infinitely large distance *x* from the river edge. The logarithmic form of the risk function is selected for convenience and simply expresses the fact that floods on rare occasions may extend further than the 100-year floodplain limits. The logarithmic risk function can be expressed as

$$r(x) = C\,10^{-Kx} \qquad \text{Eq. 1}$$

The function parameters in Eq. 1 can be easily estimated from the knowledge of the risk of exceeding the bankfull capacity flow and from the extent of the 100-year floodplain: C corresponds to the risk of exceeding the bankfull flow, or, $C = r(0)$. The risk function can be integrated across the floodplain cross-section, as shown in the following equation, in which subscripts L and R correspond to the left and right bank floodplains:

$$R = \int_0^\infty r_L(x)\,dx + \int_0^\infty r_R(x)\,dx = r(0)\int_0^\infty [10^{-K_L x_L} + 10^{-K_R x_R}]\,dx \qquad \text{Eq. 2}$$

The magnitude of the floodplain shape coefficient, K, can be obtained from the extent of the 100-year floodplain at the point of interest on the river, denoted as X_{100}, and from the risk of exceeding the bankfull discharge, $r(0)$:

$$\log\left[\frac{r(X_{100})}{C}\right] = \log\left[\frac{0.01}{r(0)}\right] = -K\,X_{100} \qquad \text{Eq. 3}$$

and

$$K = \frac{\log[r(0)] + 2}{X_{100}} \qquad \text{Eq. 4}$$

Finally, substituting for K in Eq. 2 from Eq. 4 yields the following expression for the floodplain risk parameter:

$$R = \frac{r(0)}{2.3\left(2 + \log r(0)\right)}\left[X_{L-100} + X_{R-100}\right] \qquad \text{Eq. 5}$$

The dimension of the floodplain risk parameter R is length/time, and a possible unit is meter/day. However, the unit does not have a physical meaning, as R is only a measure of the flood risk over a floodplain. R increases with an increase in the size of the floodplain and with an increase in the risk of overbank flow. This floodplain risk parameter changes along the stream. The integration of the flood risk over the watershed represents an overall risk of flooding of the watershed, the flood risk factor that can be used in comparing watershed management alternatives.

This characterization of flood risks will be used to assign unique values of flood risk to each property within the floodplain. The flood risk measure, *FRM*, calculated in GIS environment is a negative logarithm of the flood risk $r(x)$. The anti-logarithm of the flood risk measure is basically a recurrence interval, i.e., $FRM = 2$ for $T_r = 100$ years.

4. Empirical Model

a. Study Area

The study area for this analysis is located approximately 11.5 miles (18.5 km) along the middle to lower sections of the Menomonee River through the cities of Wauwatosa and Milwaukee, Wisconsin. The Menomonee River is a 71.85 (15.5 km) mile river system and discharges into the Milwaukee River about 0.9 mile upstream of where the Milwaukee River enters Lake Michigan. This region was selected to encompass two significant areas, the city of Wauwatosa and the Valley Park neighborhood in Milwaukee. Wauwatosa makes up a great portion of the study area and lies within the Menomonee River watershed boundaries. Located west of Milwaukee in northern Milwaukee County, Wauwatosa is just over 13 square miles (34 km^2) with a population of 49,300. Furthermore, it is a high density residential area, with more than 22.8 persons per net residential acre (55 persons/ha). Valley Park, the other area of concern, is the smallest and most isolated neighborhood in Milwaukee. The study area is shown in Figure 2.

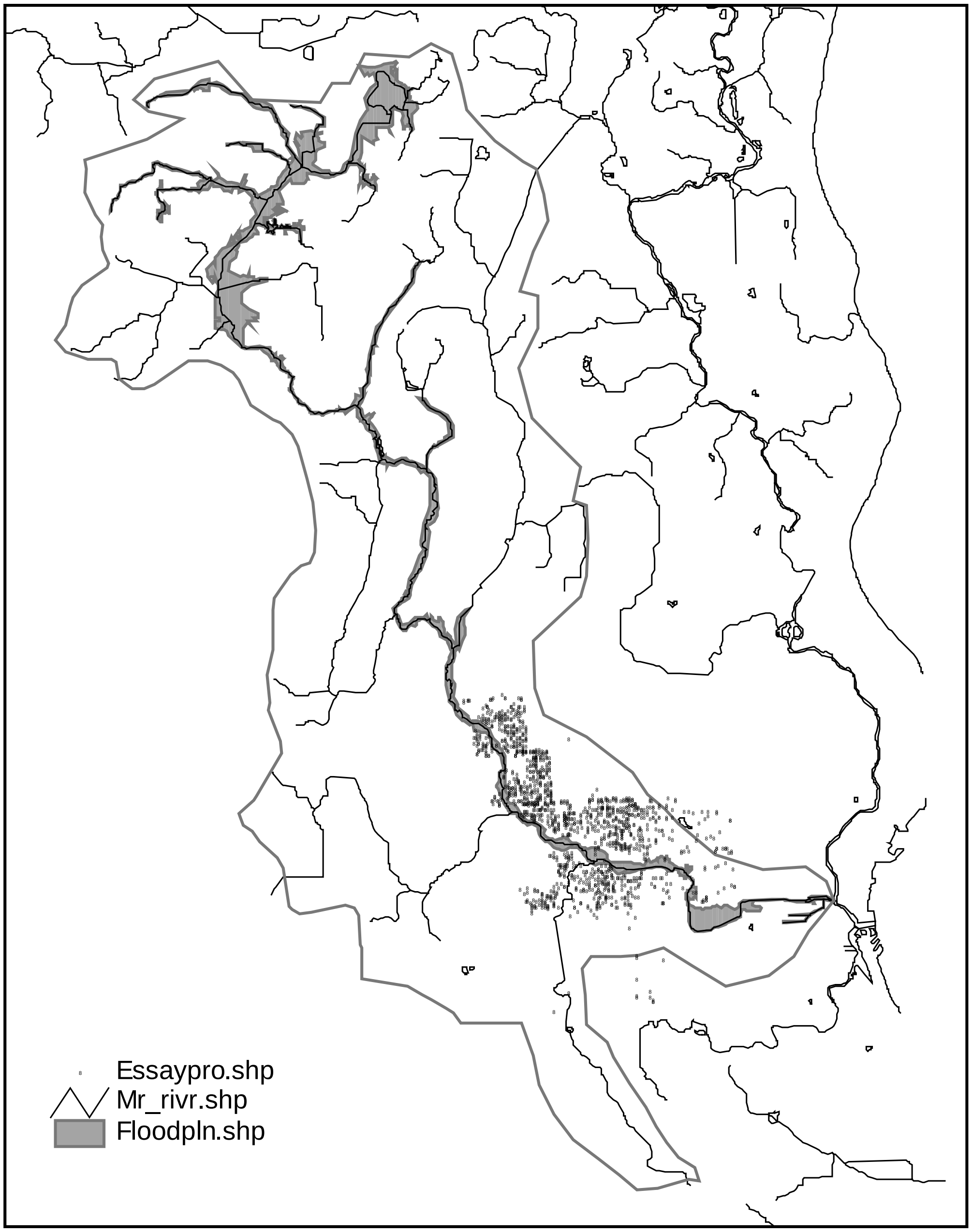

Figure 2: Menomonee River watershed. Location of properties in 100-year floodplain.

These two areas are significant for this study as a result of their susceptibility to flooding. Specifically, the study examines the short and intermediate run impacts of a 100-year flood that occurred in June of 1997. The flood was the worst rain for the Milwaukee Metropolitan area since August 6, 1986. After the first night of the rainfall, totals ranged as high as 9.78 inches (25 cm), indicating a flood recurrence interval exceeding 100 years. Roads were shut down and many residents lost power. Damage for Milwaukee County alone was estimated to be $37 million, including $24 million to residential property. About 70 homes in the County incurred major damage including collapsed basements and roofs forcing residents to evacuate their homes. Approximately 2100 homes sustained lesser damage. As a result of the flood, Wauwatosa submitted a Hazard Mitigation Grant Program application for the acquisition of a number of structures located in the floodway on the Menomonee River. They used Community Development Block Grant funds to acquire floodprone structures as a means of creating open space in the riverfront floodway. Of the 20,289 structures in Wauwatosa, about 738 are located in the special flood hazard area, 669 of which are residential. Due to its susceptibility to flood disaster, Wauwatosa was invited by FEMA in June of 1998 to participate in a nationwide effort to become a “Project Impact” community. This program would develop efforts to minimize the risk of damage from natural disasters. Valley Park also suffered from the flood in terms of water levels. However, there is a great sense of community in the neighborhood which became evident in the recovery period following the disaster. Both Wauwatosa and the city of Milwaukee, in which “Valley Park” resides, are participants in the National Flood Insurance Program (NFIP); Wauwatosa entering in 1978 and Milwaukee in 1982. The NFIP implements floodplain management regulations which ensure that development in flood-prone areas is protected from flood damages. However flood insurance is mandatory only for those properties residing within the 100-year floodplain. This increase in cost associated with location in the floodplain may reduce property value for those houses.

b. GIS Analysis

ArcView, a Geographical Information System (GIS), was used in several aspects of this study. First, it was used to spatially define flood risks. Second, properties were geocoded to the street address, and finally location specific data were matched to each property. We describe each of these activities below.

The properties were geocoded to the precise street address using the ArcView GIS package. A key to the geocoding process is the accuracy of addresses, the geographic files, and matching of the addresses to the geographic files. The addresses and geographic files received from outside sources (MLS and Wisconsin Department of Transportation) are believed to be accurate given the sources' own incentive for accuracy of the files. ArcView assigns a score to each match made for the properties. Of the 1475 observations, 1402 of them (or approximately 95%) were given a score of 75 or above on a 100 point scale. The majority of these received a score between 98-100[1]. The resulting sample size is 1431, as 44 were unable to be geocoded and eliminated from the sample. Once geocoding of properties was completed boundary files for geographic areas were digitized if they were not already available as ArcView shape files. For example, the 100 year floodplain was geocoded from FEMA maps and maps provided by the Southeastern Wisconsin Regional Planning Commission (SEWRPC). Other

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[1] A possible reason for a score at the lower end of the spectrum would be misspellings. For example, if an address appears as “Menomone Pkwy” and the correct spelling would be “Menomonee Pkwy,” the addresses may still be matched and assigned a lower score as a result. For this reason, the matches receiving a score of less than 80 were interactively re-matched by the author to ensure accuracy and minimize error.

spatial boundary data (e.g., school district boundaries, historic preservation district data) were also manually digitized.

Once the geocoding was completed, properties were matched to locational attributes of the neighborhood using one of three techniques. When a neighborhood characteristic was defined by a point in space (e.g., proximity to air quality monitors), straight line distance calculations between the property and the attribute was used. If the attribute was defined by a polygon (e.g., school districts, census block groups), then individual properties were mapped to the underlying polygon, and attributes of the polygon were attached to the property. Finally, buffers were defined for various types of line data (e.g., roads, railroads) and properties falling within the buffer zone were identified.

Turning to the calculation of property specific flood risks, two basic approaches were considered. The first is a vector-based approach that employed a custom developed ArcView Avenue scripts program. This approach permits estimation of risks only at specific points rather than for complete areas. The second more general approach works in a grid (raster) environment, and makes use of the Spatial Analyst Extension for ArcView. It permits flood risk to be calculated for the entire watershed, and specified points can be assigned the corresponding value from the underlying polygon. The second approach was selected because of its future applicability in watershed management applications.

When we refer to the floodplain in this paper, it should be understood as the 100-year floodplain. The width of the floodplain is the key parameter in calculation of the flood risk, when r(0) is kept constant. The floodplain width for any specified point, both inside and outside the floodplain, is the distance of the flood fringe from the river bank for the river cross-section on which this point is located. The calculation of the floodplain width corresponding to the selected locations had to be done separately for inside and outside of the floodplain. The floodplain width is calculated as

$$X_{100} = X_W + X_F \tag{Eq. 6}$$

or

$$X_{100} = X_W - X_F \tag{Eq. 7}$$

where X_W is the distance from the river channel and X_F is the distance from the floodplain (see Figure 3)

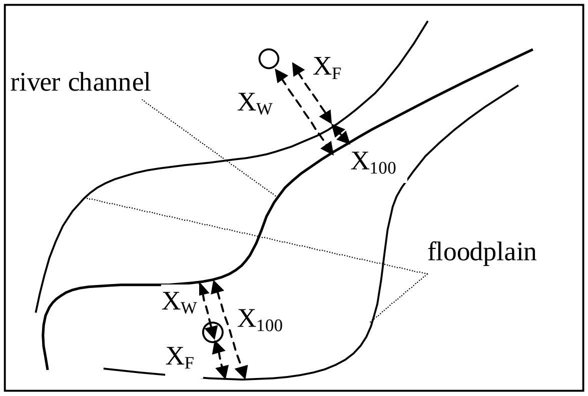

Figure 3: Calculation of floodplain width for locations inside and outside the floodplain

The floodplain was digitized as a polygon and used as such in calculations for the areas outside the floodplain. For the areas inside the floodplain, it had to be converted into a polyline and divided into several reaches. The calculation of the floodplain width for points inside the floodplain was calculated separately also for left and right banks, although the calculation followed the same procedure. The data essential for risk calculations include digitized maps of the river channel and 100-year floodplain, as well as the watershed boundaries. The risk associated with the capacity flow has been estimated separately using the information from USGS on capacity flow and the annual maximum series for the gage station in Wauwatosa. This station is located in the same area as the majority of the properties. The recurrence interval associated with the capacity flow is approximately 1 year, i.e., r(0) = 1.

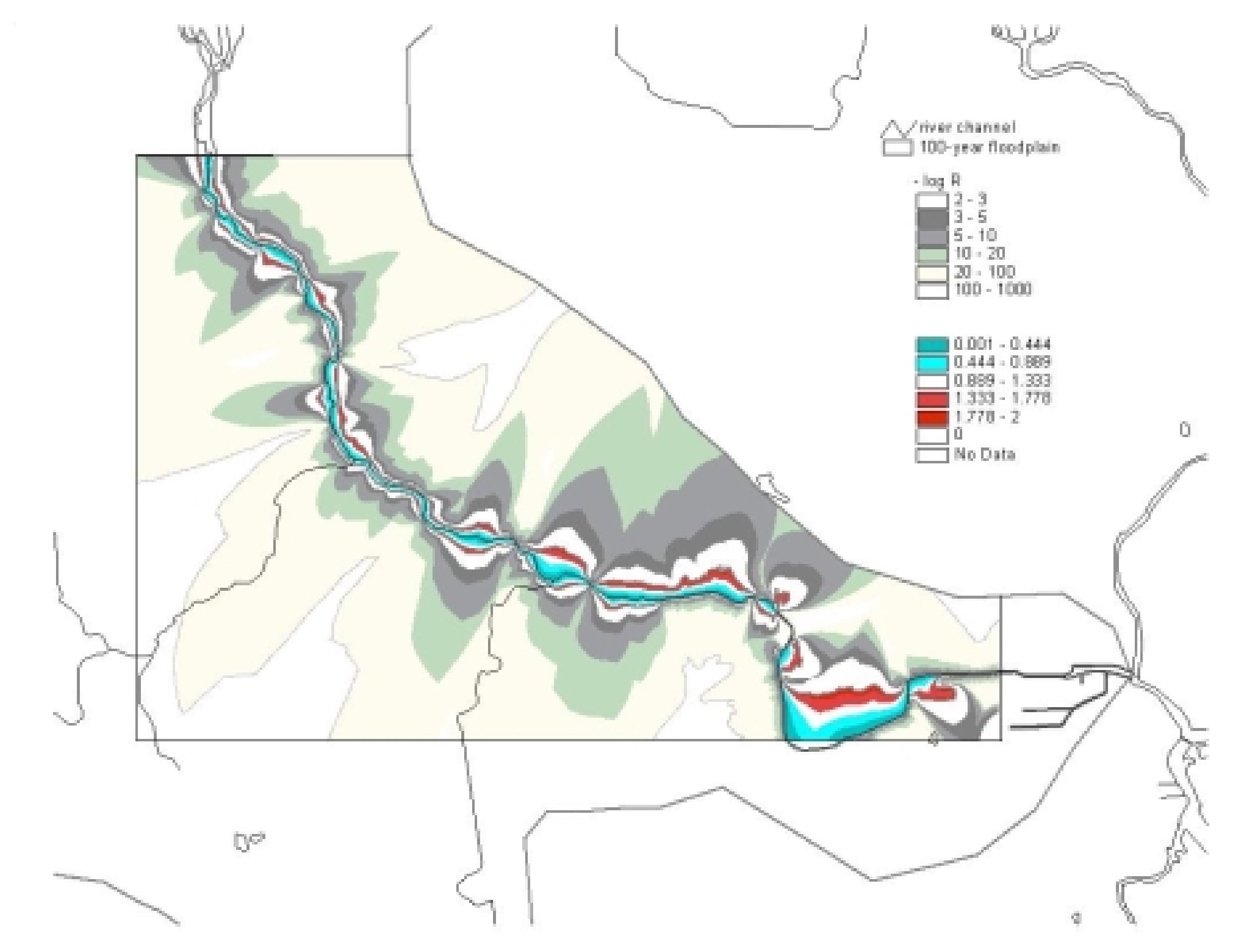

Figure 4: Flood risk measure

Figure 4 shows the flood risk measure, i.e., the negative logarithm of the flood risk, in the area where the properties are located. Individual properties were assigned a value corresponding to the underlying cell. The higher is this value, the lower is the likelihood of flooding for the specific property. An increase in this variable of one implies that flood risks decrease by an order of magnitude. For example, as you move from flood risk measure of 2 to 3 you move from a risk of 0.01 (i.e., once per 100 years) to 0.001 (i.e., once per 1000 years).

c. Description of the Data

Detailed house attribute data as well as the sales prices of the houses were obtained from the Multiple Listing Service (MLS) for the Milwaukee Metropolitan Area. Information was collected for each transaction, listed through the MLS, for the time period January of 1995- July of 1998. This time frame provides an adequate period for property value fluctuation to occur as a result of the flooding event in June of 1997, if this is the case. A total of 1,965 properties were listed through the MLS in the study area for the time period examined. From this total, properties were eliminated as a result of missing data for: the lot size (290), age of the house (198) and taxes (2). Furthermore, the MLS database only includes properties sold through realtors, and thus leaves out of the sample properties sold directly by the owner. This may reduce the possibility of including "non-market" transactions in the sample, assuming that properties sold to relatives or close friends may be transacted by this means. Finally, as noted above, 44 properties were lost as a result of geocoding difficulties, yielding a total sample of 1431 properties.

The variables in the model are organized into six categories: *Structural, Neighborhood*, *Fiscal, Disequilibrium, Time Related* and *Flood.* Many influences are controlled within the neighborhood category in order to avoid misspecification biases and to account for spatial influences. For simplicity, the fiscal variable (tax rate) and the disequilibrium control (days on the market) are included in the *Neighborhood* category for the specification. Following Cropper (et al.) a semi-log specification is chosen, and the model is specified by Eq. 8.

$$\text{LnRPRICE} = f\,(\textit{Structural},\textit{Neighborhood},\textit{Time Related},\textit{Fiscal},\textit{Disequilibrium},\textit{Flood}) \quad \text{Eq. 8}$$

The variable definitions and data sources are reported in Table 1, and descriptive statistics are in Table 2. The dependent variable is the log of real sale price of housing and is deflated by the housing component of the CPI (1982-84) for the month in which the property sold.

i. ***Structural*** **Variables**

The structural characteristics include the number of bedrooms, bathrooms, other rooms, presence of an attached garage, as well as square footage of the lot and the property. It is expected that an increase in any one of the previous characteristics will increase the sale price, assuming that these attributes increase the housing services a property provides. Measures of area are included in linear and quadratic form to account for nonlinearity in these variables. Finally, the age of the house is included expecting a negative relationship between the age of the house and the sale price. This is based on an assumption that older homes may have dated technology lacking several beneficial features that would increase the housing service provided by the property.

ii. ***Locational*** **Variables**

Each property was matched to numerous locational variables, including those in the *Neighborhood* category. To account for various demographic characteristics, census data was attached accordingly to the appropriate property. The census block group data captures the racial and ethnic mix of the neighborhood. The sign for these variables cannot be predicted without knowledge of a home purchaser's cultural preferences. The characteristics also include measures of income and poverty, home occupancy, age of the neighborhood. Also, the model controls for the travel time to work and the population density of the neighborhood. The latter variable is included to control for aspects of the neighborhood correlated with density which are not measured (eg., crime, cultural amenities).

The property tax is included to account for fiscal effects, expecting that increases in taxes would decrease the sale price. Also capturing fiscal impacts is the teacher student ratio for the high school district in which the property resides. A dummy variable is included to account for residence within Wauwatosa or Milwaukee, which may capture a submarket influence and perceptions associated with living in Wauwatosa (versus Milwaukee). The number of days a property was on the market is used in the model as a disequilibrium control variable.

Past studies have found historical preservation districts to positively impact property values (Clark and Herrin 1997; Coffin 1989). The coefficients may be positive in the case that creation of the district provides people with additional information about the housing stock and revitalizes the neighborhood, yet also may be negative if the structural restrictions reduce housing demand. There are a total of six preservation districts in this study area, three in Milwaukee and three in Wauwatosa. Dummy variables are included for each of the districts.

As indicated in the theoretical review of the hedonic price model, one of the influences on the property sale price is environmental quality. Several variables controlling for environmental quality factors are included within the neighborhood category including measures of air quality, and proximity to Toxic Release Inventory sites. Accounting for the impact of local annoyance factors is the proximity to both highways and rail lines, as well as residence on a major road. One would expect these factors to negatively affect property sale price in most cases. A variable is also included to capture scenic benefits of residing along the river, a positive environmental attribute. This is measured by a dummy variable for those properties residing on the Menomonee River Parkway. While some of the properties along the Menomonee River Parkway may also be susceptible to flooding, only 7 of the 13 properties along the Parkway are also in the 100-year floodplain. Thus, the effect of this variable should pick up the scenic benefits of the river, while holding constant the risk associated with flooding (accounted for by variables in the *Flood* category).

iii. *Time Related* Variables

The model also includes dummy variables in the *Time Related* category for both the year and season in which the property was sold. Business cycles may affect property values, and the year variables are incorporated to capture the possibility of that influence. Furthermore, the year variables may capture an interest rate effect. Similarly, the season dummies control for trends that may be associated with time. There are no expected signs for the variables relating to time.

iv. *Flood* Variables

Finally, variables representing the focus of this study are included in the *Flood* category and also capture environmental quality. Other studies (Speyer and Ragas 1991, Schaefer 1990, Donnelly 1989, Park and Miller 1982, Thompson and Stoevener 1983) have used dummy variables accounting for a property's location inside or outside of the 100-year floodplain. All, with the exception of Schaefer, have found a significant negative relationship between location in the floodplain and the sale price of a property. This study differs from the previous studies in that a continuous measure of risk is derived. This permits floodplains of any periodicity to be defined. We investigate floodplains in 100 year increments from 100-500 year floodplains. Over the 3 year period, 15 properties sold in the 100-year floodplain, and 32 sold within the 500 year floodplain. In addition, we examine the rate at which property values change within each increment.

A second objective is to analyze the short run and intermediate run effects of a specific flood event that occurred in June of 1997. To do so, two different measures are used. First, to measure the short run impact, the floodplain dummy is interacted with a dummy variable for whether the property was sold after the flood event. Of the 1431 properties in the sample, 512 of them were sold after the flood event and 4 of these were within the 100-year floodplain whereas 12 were within the 500-year floodplain. Second, to measure intermediate run effects, the floodplain dummy is interacted both with the dummy for whether the property was sold after the flooding event and the number of days between the flooding event and the sale of the house. If present, one would expect short run effects to be stronger than intermediate impacts, assuming that the consequences of the flood event will taper off in the minds of homeowners and buyers as time passes.

5. **EMPIRICAL FINDINGS**

The coefficients on control variables in the *structural*, *neighborhood, fiscal, disequilibrium* and *time related* categories differ minimally among the tables. To conserve space, these variables are reported only once, with subsequent regressions reporting only the flood category variables. Heteroskedasticity, a non-constant variance in the model's error term, is expected in this sample of data since variance in selling price is likely to differ between the low-end and high-end of the market. To test for the presence of heteroskedasticity, White's test is used and the null hypothesis of no heteroskedasticity is rejected at the 95% level of confidence for each regression (Gujarati, 1995). White's correction is employed to generate consistent estimates of the standard errors. All models estimated explained approximately 91% of the variation in the real housing price.

i. *Structural* Variables

All structural variables are significant at the 99% level of confidence, except the dummy accounting for whether the garage is attached. The number of garage spaces is significant, with each additional space increasing the value of the home by 4.8%. The number of bedrooms, other rooms, half baths, and full baths all positively impact property sale price. One additional half bath, full bath, bedroom, and other room, increases the property value by 11.2%, 6.2%, 5.0%, and 5.8% respectively. The large magnitude of the coefficient on the half bath variable suggests that it may be serving as a proxy for other structural features of the house. Both square footage variables, interior and lot, increase property value at a decreasing rate reflected by positive linear terms and negative quadratic terms. The partial derivative of sale price with respect to the interior square footage (∂Real Price/∂Building area) is equal to [β_{AREA} + 2 *β_{AREASQ}*Building area]. Evaluated at the mean for interior square footage (705.7 sq.ft. or 0.65 m^2), property value increases by 6.8% for an increment of 100 square feet (or 0.72%/m^2). Similarly, an increment of 1000 square feet for the lot size increases sale price by 1.7% (or 0.18%/m^2 evaluated at the mean). Finally, other things equal, age has a negative effect on property value (i.e., 1.6% for each additional 10 years). Inclusion of a quadratic term for age made both the linear and quadratic terms insignificant.

ii. *Locational* Variables

Evaluating the demographic variables taken from the block group data, many coefficients appear to be significant at the 99% confidence level. Exceptions include population density and the percent of occupied housing units, and percent owner occupied units. Population density has a negative relationship with property value suggesting that on the net, urban scale related disamenities have a stronger influence than that of amenities, yet the variable is insignificant. The racial variables reveal that higher concentrations of Asian (as compared to nonwhite other race) populations in a neighborhood positively affect property values. Specifically, a 1% increase in the Asian population increases property value by 3%. The impact of Hispanic populations, on the other hand, decrease real home sale prices by 2.5%. Percent White is positive and significant, raising prices 1.3% per 1% increase, whereas percent Black is not significant. Note, that most of the neighborhoods in the study areas have relatively few minority households. As expected, higher poverty rates in a neighborhood decrease home sale price, yet the effect is not great. Median household income, also reflecting socioeconomic dimensions of the neighborhood, positively impacts property values. Measured by the median year of houses built in the neighborhood, older neighborhoods have significantly higher priced housing in the study area. This is somewhat contrary to the sign on the age variable, yet it may suggest that people prefer historic surroundings in a neighborhood along with the benefits of a technologically advanced home. Finally, in line with the existing theory, each additional 10 minutes of commute time decreases the home sale price by 9%.

The tax rate, incorporating fiscal effects into the model, negatively impacts property value. Specifically, a 1% increase in the property tax rate (e.g. 4.3% to 5.3%) decreases the property sale price by 2.0%. The teacher student ratio included to proxy the quality of education does have a positive effect, yet is insignificant. Also insignificant is the number of days a house was on the market. The dummy variable accounting for city jurisdiction is significant indicating higher sales prices (by a magnitude of 19%) in Wauwatosa than in Milwaukee. However, Valley

Park is only one small area in Milwaukee and the dummy accounting for location in Valley Park was insignificant.

The effect of historic preservation districts was positive in all cases confirming that historic preservation districts provide home buyers with additional information regarding the housing stock and serve the purpose of revitalizing the neighborhood. The influence of five of the six districts was significant. The most dramatic of all influences was that of The McKinley Boulevard Historic District in Milwaukee, increasing property value by 49%. The Concordia Historic District, also in Milwaukee, has a similar effect with 41% increase in property value as a result of residing within the district. The one historic preservation district that did not have a significant impact was The Wauwatosa Avenue Historic District. These districts were also interacted with age, yet the resulting variables were insignificant and doing so overwhelmed the significance of the individual dummies. Therefore, they were not included in the final regression.

Several other variables in the neighborhood category were indicative of the surrounding environmental quality. The quality of the air measured by the sulfur dioxide reading negatively impacts property sale price as we would expect, and this effect is significant at the 99% level of confidence. Furthermore, location within one mile of a Toxic Release Inventory site has the effect of reducing home sale prices by 2.8%, all else constant. Two of the variables representing local annoyance factors significantly reduce the sale price of a home. Specifically, residence on a major road and residence within a quarter of a mile of rail lines reduce home sale prices by 5.7% and 6.0% respectively. On the other hand, residence within a quarter of a mile of Interstate 94 increased sales prices for homes by 8.5%. It is possible that this variable is controlling for non-work related travel accessibility in addition to an annoyance factor. Finally, residence along the scenic Menomonee River Parkway has the significant effect of increasing property value by 7.1%, all else constant.

iii. Time Related Variables

The seasonal dummy variables are insignificant indicating that the season in which a house is sold has no impact on the sales price. The year dummy variables indicate that real housing prices have fallen over the time period 1995- July of 1998. The effect in 1996 is insignificant; however, housing prices significantly decreased for both 1997 and 1998.

iv. Flood Variables

There are two objectives in terms of flood risk for this study. The first objective is to determine the effect that flood hazard in general has on property value. In the first regression reported in Table 3, we proxy flood risk using the negative log (base 10) of the expected flood frequency , i.e., flood risk measure (see Figure 4). The log of the value is included due to the rapid rate at which flood risks fall as distance from the river increase, and elevation rise. The findings indicate a clear relationship between reduced flooding risk, and increased property values. However, the value of the coefficient is extremely low. This finding is not surprising, given that the vast majority of properties are well beyond even the 1000-year floodplain. Hence a reduction of risk from say 10E-23 to 10E-24 is of negligible value to those residents.

To investigate the variation of flood risks within floodplains, we explore several different specifications. First, we examine the 100-year floodplain. Although flood risk is continuously defined, lenders only require that properties in the 100-year floodplain purchase flood insurance. In Table 4, we report the findings on a regression that includes a dummy variable for whether the property lies within the 100-year floodplain. In addition, we interact that variable with the recurrence interval, i.e., anti-log of the flood risk measure. The recurrence interval takes on values between 6.3 (i.e., a flood is expected with a probability of 1/6.3) for the property closest to the river, and 100 for a property at the edge of the 100-year floodplain. Both the dummy variable and risk interaction term are statistically significant. The findings suggest that properties at the edge of the river would sell for approximately 7.8% than those outside the floodplain. However, as flood risk diminishes by 10 years (e.g., from a one-year flood frequency to an 11-year frequency) property values would increase by 2.3%. This implies that the detrimental effect of the flood risk is eliminated after the expected flood risk falls to once every 33.3 years.

In Table 5, we add a second interaction term to consider the effect of a flooding event. The variable *Days since* is the number of days since the flood in June of 1997. Hence, it measures the effect of the flooding event on the impact of the 100-year floodplain. The inclusion of this variable renders the floodplain dummy variable insignificant, although it remains negative. This is due to multicollinearity between the two variables. Treating the coefficient on the dummy variable as point estimate, it suggests that properties (at the edge of the river) selling in the floodplain prior to the flood sold for 5.1% less than comparable properties outside the floodplain prior to the flood. Those selling a year after the flood would sell for 18.9% less than properties outside the floodplain. The pattern did not appear to be nonlinear, although note that it was not possible to capture longer-term effects due to the fact that the sample did not extend further into the future. Thus, it appears that at least over the short term, the flooding event did reduce property values beyond what they were prior to the flood.

In the final model presented in Table 6, we explore whether wider floodplains generate detrimental effects on properties within those areas. Thus, we define floodplains between 100 and 200 hundred years, 200 and 300 years, and so on. Given that the detrimental effects of flood risk appear to dissipate within the 100-year floodplain, it is not surprising that none of the other floodplain categories are negative and significant. Indeed, the region between the 300 and 400-year floodplain sells at a premium over those outside the floodplains. We also explored whether the flooding event negatively influenced any of the property values within the 200 year and beyond areas, and found no evidence of detrimental impacts.

6. Conclusions

This study employed GIS tools to more accurately characterize flood risks in an urban watershed. An interpolation scheme to evaluate the level of flood risk in the watershed has been developed and applied to the Menomonee River watershed. Together with a wide range of other locational attributes, flood variables were matched to geocoded properties to investigate impacts on housing prices. Our findings support the hypothesis that increases in flood risk decrease values for residential properties within the 100-year floodplain. Unlike other studies which conclude that there are uniform impacts within the floodplain, we find declining effects with reduced risk. Furthermore, there is evidence suggesting that flooding events heighten sensitivity to such risks and raise the property price premium associated with a given level of flood risk. Negative impacts beyond the 100-year floodplain are not found.

The use of GIS tools to complement statistical analyses of urban spatial problems will continue to grow as PC-based GIS software becomes more powerful, and geographic data sources more abundant. In addition, GIS tools can serve as a conduit for interdisciplinary work as geographic modeling in the physical sciences and engineering is integrated with spatial modeling by social scientists.

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Table 1: Variable Definitions and Data Sources

Dependent Variable and Variables in the *Structural* Category

Variable Name	**Definition** **[mean, standard deviation]**	**Source**	**Predicted Sign**
Real Price	Real sale price of the property (1982-84 dollars)	MLS	LnRPRICE is the dependent variable
Age house	Age of the house in years	MLS	-
Full bath	Number of full baths in house	MLS	+
Half bath	Number of half baths in house	MLS	+
Bedrooms	Number of bedrooms in house	MLS	+
Other rooms	Total rooms minus number of bedrooms	MLS	+
Building area	Area of the master bedroom+bedroom2+livingroom+kitchen in square feet Note: Due to data limitations, all of the square footage is not captured	MLS	+
Garage spaces	Number of garage spaces	MLS	+
Garage attached	1 = garage attached, 0 = otherwise	MLS	+
Lot size	Lot area in square feet	MLS	+

Variables in the *Neighborhood, Fiscal, and Disequilibrium Control* Categories

Variable Name	**Definition** **[mean, standard deviation]**	**Source**	**Predicted Sign**
Sulphur Dioxide	Distance weighted value of the nearest air monitor, computed as sulfur dioxide/distance of monitor to property	LandView III	-
Major road	1 = property resides on a primary road, 0 = otherwise	ArcView	-
Menomonee Parkway	1= property resides on the Menomonee River Parkway, 0 = otherwise	ArcView	+
¼ mile I94	1= property within a quarter of a mile of Interstate 94, 0 = otherwise	ArcView	-
Commute time	Average household travel time to work for the block group in minutes	1990 Census of Population and Housing	-

Variable Name	**Definition** **[mean, standard deviation]**	**Source**	**Predicted Sign**
¼ railroad	1= property within a quarter of a mile of railroad tracks, 0 = otherwise	ArcView	-
Toxic Release Inv.	1= property within a quarter of a mile of a manufacturing facility on the Toxic Release Inventory, 0 = otherwise	BASINS	-
Historic Preservation Districts	HPDTOSA 1= resides within The Wauwatosa Avenue Historic District, 0= otherwise HPDCHURCH 1= resides within The Church Street Historic District, 0= otherwise HPDWASH-HIGH 1= resides within The Washington Highlands Historic District, 0= otherwise HPDCONCORD 1= resides within The Concordia Historic District, 0=otherwise HPDMCKINLEY 1=resides within The McKinley Boulevard Historic District, 0=otherwise HPDHIMOUNT 1= resides within The Washington-Hi Mount Boulevards Historic District, 0=otherwise	Maps received from: Wauwatosa City Planning (first three) Milwaukee City Planning (last three)	
TS ratio	Teacher student ratio for the school district in which the property resides	Respective High Schools	+
Pop density	Population density in the block group, measured as people per square mile	1990 Census of Population and Housing	?
Median year built	Median year of houses built in the block group	1990 Census of Population and Housing	?
Median HH income	Median household income of the block group	1990 Census of Population and Housing	+

Variable Name	**Definition** **[mean, standard deviation]**	**Source**	**Predicted Sign**
%Asian	Percent of the block group population that is Asian	1990 Census of Population and Housing	?
%Black	Percent of the block group population that is Black	1990 Census of Population and Housing	?
%Hispanic	Percent of the block group population that is Hispanic	1990 Census of Population and Housing	?
%Other	Percent of block group population which falls into the "other" category	1990 Census of Population and Housing	+
%Occupied units	Percent of the block group housing units that are occupied	1990 Census of Population and Housing	+
%Owner occupied	Percent of block group housing units that are owner occupied	1990 Census of Population and Housing	+
%Poverty	Percent of block group population that is below the poverty line	1990 Census of Population and Housing	-
Tax rate	Tax payment / [sale price/1000]	MLS	-
Wauwatosa	1 = property resides in Wauwatosa, 0 = Milwaukee	MLS	+
Valley Park	1 = property resides in Valley Park, 0 = otherwise	ArcView	?
Days on market	Number of days the house was on the market	MLS	-

Time Related Variables

Variable Name	**Definition [mean, standard deviation]**	**Source**	**Predicted Sign**
Seasonal Dummy Variables	SPRING=1 (March-May),0=otherwise SUMMER=1 (June-Aug), 0=otherwise FALL=1 (Sept-Nov), 0=otherwise WINTER=1 (Dec-Feb), 0=otherwise	MLS	? Winter is omitted variable
Year	1= dwelling sold in ith year, 0=otherwise i = 1995, 1996, 1997, 1998	MLS	? 1995 is omitted variable

Variables in the *Flood* Category

Variable Name	**Definition [mean, standard deviation]**	**Source**	**Predicted Sign**
Floodplain$_{100}$ Floodplain$_{200}$ Floodplain$_{300}$ Floodplain$_{400}$ Floodplain$_{500}$	1= resides in the 100-year, 0=otherwise 1= resides in space beyond 100 year flood and within 200 year flood, 0=otherwise 1= resides in space beyond 200-year and within 300 year flood, 0=otherwise 1= resides in space beyond 300-year and within 400 year flood, 0=otherwise 1=resides in space beyond 400-year and within 500 year flood, 0=otherwise	ArcView	**-**
Flood Risk Measure	Minus log of flood risk	Arcview	**+**
Recurrence Interval	The expected number of years between flooding events	ArcView	**+**
After	1= after the June 1997 flood, 0 = otherwise	ArcView	**?**
Days since	The number of days since the June 1997 flood.	ArcView	**?**

Table 2: Descriptive Statistics

Dependent Variable and *Structural Characteristics:*

Variable	Mean	SD	Maximum	Minimum
RPRICE	79048.1	34708.90	360962.6	7348.029
Agehouse	59.970	16.678	138	1
Full bath	1.278	0.487	4	1
Half bath	0.423	0.497	2	0
Bedrooms	3.211	0.741	7	2
Other rooms	3.488	0.990	8	0
Building area	705.214	155.137	1917	400
Garage space	1.793	0.639	4	0
Garage attached	0.193	0.395	1	0
Lot size	7081.323	3768.827	58344	1381

Variables in *Neighborhood, Fiscal, and Disequilibrium Control Categories*

Variable	Mean	SD	Maximum	Minimum
Sulpher Dioxide	153080	53632.03	504252	91485.71
Major road	0.062	0.241	1	0
Menomonee Parkway	0.009	0.094	1	0
¼ mile I94	0.042	0.200	1	0
Commute time	16.991	2.239	32.633	12.435
¼ mile railroad	0.093	0.291	1	0
Toxic Release Inv.	0.468	0.499	1	0
HPD Tosa	0.006	0.078	1	0
HPD Church	0.006	0.078	1	0
HPD Wash. Highlands	0.003	0.058	1	0
HPD Concord	0.003	052	1	0
HPD McKinley	0.004	0.064	1	0
HPD Himount	0.008	0.087	1	0
TS ratio	0.118	0.082	0.21	0.03
Pop. Density	7247.6333	3530.725	27743.90	752.500
Median Year Built	1945.530	7.017	1975	1939
Median HH income	40259.25	11716.96	66,649	7557
%ASIAN	1.137	1.754	18	0
%BLACK	2.970	11.040	90	0
%HISPANIC	1.369	1.537	13	0
%OTHER	0.460	0.906	9	0
%OCCUPIED	0.977	0.024	1	0.765
%OWNEROCC	72.808	18.028	99	5

%POVERTY	5.021	9.20	81	0
Taxrate	0.028	2.181	0.077	0.009
Valley Park	0.009	0.094	1	0
Wauwatosa	0.633	0.482	1	0
Days on Market	54.023	67.673	1095	0

Time Related Variables

Variable	Mean	SD	Maximum	Minimum
Spring	0.282	0.450	1	0
Summer	0.336	0.472	1	0
Fall	0.234	0.424	1	0
Winter	0.401	0.490	1	0
Year95	0.157	0.364	1	0
Year96	0.302	0.459	1	0
Year97	0.321	0.467	1	0
Year98	0.220	0.414	1	0

Flood Related Variables

Variable	Mean	SD	Maximum	Minimum
Flood Risk Measure	24.562	26.104	179.42	0.8
Recurrence Interval$_{100}$	36.9	29.258	100	6.8
Recurrence Interval$_{500}$	174.102	167.652	489.778	6.8
Floodplain$_{100}$	0.0105	0.102	1	0
After	0.358	0.479	1	0
Days since	69.317	113.661	397	0

Table 3 – Hedonic Regression with Log Flood Risk

Variable	***Coefficient***	***t-score***	***Variable***	***Coefficient***	***t-score***
Intercept	10.81558	3.3085			
Structural Characteristics			*Time Dummy Variables*		
Agehouse	-0.001594	-3.149	Year 1996	-0.014904	-1.295
Bedrooms	0.049593	7.0307	Year 1997	-0.075591	-6.212
Full bath	0.061932	6.0275	Year 1998	-0.079498	-5.296
Half bath	0.112181	12.078	Spring quarter	-0.00728	-0.595
Other rooms	0.057908	11.015	Summer quarter	-0.009696	-0.845
Garage space	0.047633	6.6189	Fall quarter	-0.001184	-0.093
Garage attached	0.013503	1.1273	*Historic Preservation Districts and locational variables*		
Building area	0.001224	10.133	HPD Church	0.063261	2.982
Building area * Building area	-3.85E-07	-5.542	HPD Concordia	0.412596	3.312
Lotsize	2.10E-05	6.7995	HPD High Mount	0.141946	2.039
Lotsize*Lotsize	-2.49E-10	-4.832	HPD McKinley	0.486035	5.299
Neighborhood and Fiscal Characteristics			HPD Wauwatosa	0.069102	1.198
Sulpher Dioxide	-1.16E-06	-3.134	HPD Wash. Highlands	0.213099	8.95
Major road	-0.057245	-3.99	Wauwatosa	0.198344	10.31
¼ mile I94	0.084733	3.1272	Valley Park	-0.023755	-0.264
¼ mile railroad	-0.059753	-3.279	Menomonee Pkwy	0.071265	1.795
Commute time	-0.008686	-4.69	*Flood Risk Variables*		
Toxic Release Inv.	-0.027812	-2.633	Flood Risk Measure	0.000253	2.003
Teacher Student ratio	0.028262	0.3231	*Disequilibrium Control*		
Population Density	-2.91E-06	-1.355	Days on market	-8.17E-06	-0.115
Median HH Income	3.07E-06	3.9097			
%Asian	0.030403	4.2097			
%Black	0.006825	1.1918			
%Hispanic	-0.02546	-3.941			
%White	0.013137	2.3295			
%Owner occupied	-0.000667	-1.26			
% Occupied units	-0.001439	-0.003			
% Poverty	-0.004957	-3.852			
Tax rate	-0.020374	-19.32			
Median year built	-0.003079	-1.894			
R-squared	0.917731		Adjusted R-squared	0.914996	
Mean dep. variable	6.574281		S.E. of regression	0.137611	
F-statistic	335.6265		Log likelihood	831.532	

Table 4: Model II—Flood Risk within the floodplain

LnRPRICE = *f* (*Structure, Neighborhood, Time Sold, Flood*),

Variable	Coefficient	t-statistic
Floodplain_{100}	-0.078337	-1.931
Floodplain_{100}*Recurrence Interval	0.002332	3.4425

Table 5: Model III—Flood Risk and a Flooding Event

LnRPRICE = *f* (*Structure, Neighborhood, Time Sold, Flood*),

Variable	Coefficient	t-statistic
Floodplain_{100}	-0.050991	-1.041
Floodplain_{100}*Recurrence Interval	0.002091	2.6966
Floodplain_{100}*Days Since Flood	-0.000378	-2.233

Table 6: Model III—Flood Risk in Expanded Flood Zones

LnRPRICE = *f* (*Structure, Neighborhood, Time Sold, Flood*),

Variable	Coefficient	t-statistic
Floodplain_{100}	-0.05261	-1.064
Floodplain_{100}*Recurrence Interval	0.002184	2.5027
Floodplain_{100}*Days Since Flood	-0.000366	-2.177
Floodplain_{200}	-0.020201	-0.323
Floodplain_{300}	-0.046497	-1.366
Floodplain_{400}	0.143638	4.87
Floodplain_{500}	-0.007187	-0.118

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