Australasian Transport Research Forum 2011 Proceedings
28 - 30 September 2011, Adelaide, Australia
Publication website: http://www.patrec.org/atrf.aspx

An Economic Basis for Projecting Land Use Development

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Abstract

In recent years there has been an increasing requirement for local government authorities to develop detailed infrastructure plans to support government, infrastructure providers and the development industry in future planning. Historically there has been very little in the way of analytical tools to inform this process.

TransPosition has developed a model for projecting changes in land use in defined areas using an economic model of development profitability. This determines the sequencing of development of all types according to estimates of population and employment growth over time.

This model takes detailed land use data down to the lot level with individual properties and buildings identified, combined with local street and lot level accessibility data to generate an extremely detailed pricing model to determine viability and profitability of competing development options. The development timeline is controlled to top-down totals for population and employment by type, ensuring projections that are completely consistent with higher level demographic and economic forecasts.

The model organically deals with topographical, environmental, heritage and other factors by treating them as constraints in the same process in which the planning scheme is assessed. Scenario testing, such as examining the viability of planning scheme, regulatory or other changes are simply performed by expressing them as overlaid constraints.

A description of the successful implementation of this model in the Brisbane local government area as well as potential for further development is discussed.

1 Introduction

Land use projections have traditionally been largely performed simply as an input or adjunct to transport models for the purpose of determining such as things as changes in trip generation and attraction over time. The modelling approach described here views land use as an important outcome in itself and also builds the basis of a two way interaction between land use and transport modelling. In fact, the ultimate aim is to generate complete urban or regional models that are used to project land use outcomes, transport system efficiency and effectiveness, demography and economic activity from a single system.

This paper describes a new approach to land use projections that is tightly integrated with a transport accessibility model and which uses an economic basis for predicting the nature and sequencing of development over time. An application of the model in the Brisbane City Council area and recommendations for further work is then briefly described.

2 Literature review

Bravo describes a model for implementing an integrated land use/transport system where the land use interaction is modelled as a fictitious set of nodes on the transport network (Bravo et al 2009). The system is able to use established transport modelling techniques to generate an equilibrium state of transport and land use. The system includes congestion effects as an externality. A major weakness is that the system only supports private vehicle transport. This effectively cuts the choice framework down substantially. For example, one of the major policy positions of modern urban planning is the development of “transit oriented developments” (TOD). A TOD, by definition, is based on both pedestrian and public transport accessibility, so excluding these from the transport/land use model effectively renders it unable to deal with this important emerging aspect of urban development.

Gregor advocates a practical approach to land use modelling, focusing on the minimal set of features necessary to achieve a realistic set of projections (Gregor 2007). The main limitations of land use models are given to be complexity, long run times and unreliability at the disaggregate level. The complexity of developing useful land use models centres around the difficulty in obtaining complete data on existing land use. This is a very real problem that we will discuss further. Long run times is a general problem that plagues every modeller and almost certainly will forever. While processor speed, storage and network capacity have and continue to expand exponentially, the complexity of the questions we ask of computer models has had no difficulty in keeping pace. Gregor identifies the issue as being the inability to perform a large number of runs to develop a sense of the sensitivity of the system to different input conditions etc. Ideally then, a system would enable a partial rerun of a model with only the pertinent changes being re-implemented. For example, if the starting conditions were the same but a behavioural change were input, then only the parts of the model that would be affected by that change would be recalculated. The final identified problem is that of unreliability at the disaggregate level. That is, that different models can produce very different results when looked at in detail. Gregor describes a model called LUSDR, which uses a synthesized set of households acting as agents generating decisions around land use. This, however, inevitably produces a great deal of complexity in the development and calibration of this set of households. Modelling the demand for generation of new land use development as a simple market system would remove this complexity.

Martínez describes a stochastic auction process for determining land use outcomes (Martínez 2006). This process would be likely to encounter all of the problems identified in Gregor (2007). It would entail substantial complexity of data requirements, certainly increased computational cost and would not generate predictable or repeatable outcomes at the disaggregate level. It is also not clear that the process can produce more useful results given the inherent lack of precision in the data and modelling process. As the practical purpose of land use models is to identify things such as infrastructure requirements, economic effects and demographic implications, the inherent (and largely unknowable) variation of land use changes on a lot by lot basis is not generally an interesting or reliable result.

Krumdieck describes a method for projecting the impact of peak oil to urban form and activities involving transport and land use (Krumdieck 2010). The impact of peak oil occurring on each of four different urban forms is described. While in each case travel and fuel use declined as a result of peak oil, there were different risks to activities based on urban form. It follows then, that if land use and transport networks form a single system, then land use impacts will follow. The consequence is that combined transport/land use models need to be able to flexibly incorporate economic and behavioural changes to examine the sensitivity of future land use changes to these effects.

3 Description of the modelling process

3.1 Introduction

Any model of development needs to consider aspects of supply and demand. Supply side constraints place limits on where development can occur and what the type and intensity of development is possible. Construction cost, development costs and infrastructure charges also impact on the feasibility of supplying new developments. On the demand side, the overall growth in population and employment in the region provides the basis for demand. At a local level, the attractiveness of the site for its proposed use will influence how large the market is for the site, and thus how much it is likely to cost to purchase.

Obviously all of these factors are complicated, and so to make a tractable model the situation must be simplified. The approach used by this model is to assume that development is driven by profitability calculations of developers. At any point the profitability of development on a lot can be calculated by finding the most valuable use for the lot subject to constraints and subtracting the cost of acquiring the lot and paying for the development. The model assumes that the value/price of a lot is a function of accessibility and size – those locations that are well located will achieve high values. The accessibility will be different for different land uses; residential locations are more valuable if they are close to schools, shops and jobs; industrial locations are more valuable if they are close to ports, highways and other industrial land.

3.2 Model summary

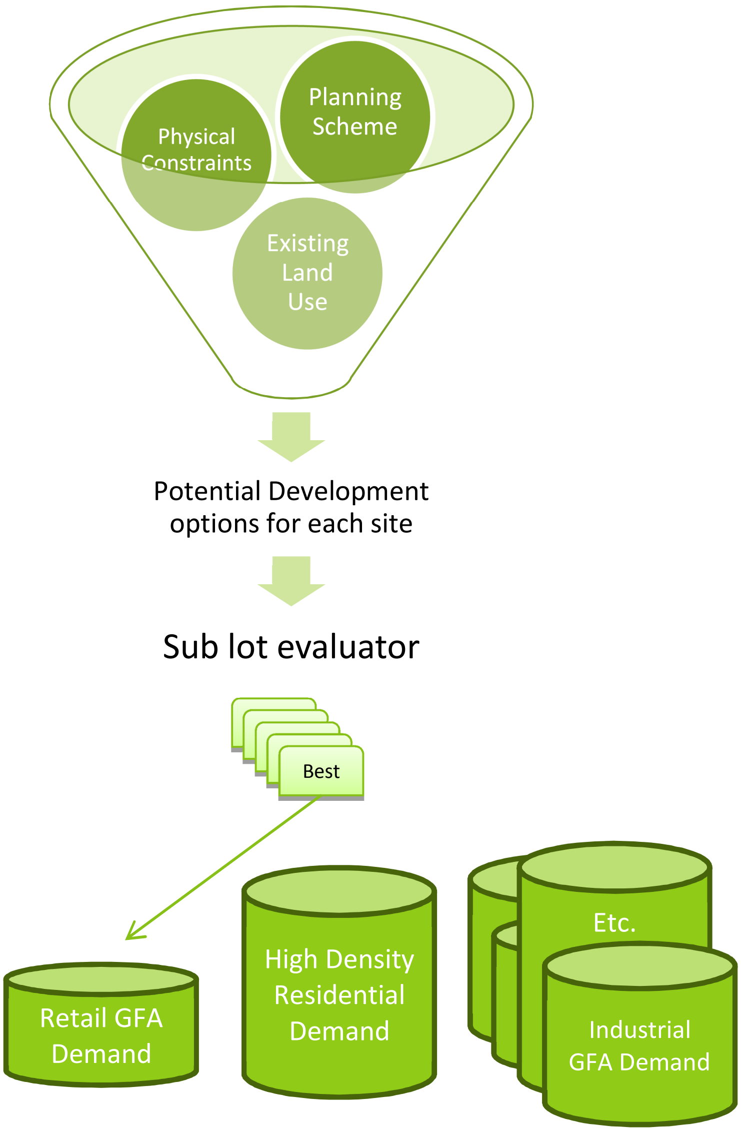
The model contains three high level elements.

The first element is the generation of development options for each site, taking into account the existing land use, the planning scheme, and any physical or environmental constraints. These include eco-physical constraints (waterways, slope, acid-sulphate soils etc.), and regulatory constraints (planning scheme, neighbourhood plans, scenarios), which are combined to give rules on what can be developed. Each lot is considered in light of the rules to identify all possible developments on the site (including sub-lot analysis)

Then development options are evaluated to calculate profitability. Each potential use on each sub-lot is evaluated to determined how attractive it is for development.

Then the most valuable developments of each type are allocated, subject to the top-down regional demand for that type of development. All possible developments across all possible land uses are ranked in single list. Developments are then allocated to buckets of demand for each land use. The demand is determined from the top down population and employment forecasts.

Figure 1 - a conceptual overview of the development option generation and assignment process. Physical constraints, the planning scheme and the existing land use are used to generate potential developments which are then assigned in order of profitability.



3.3 Options generation

In order to generate options for each lot, all relevant constraints must be considered. For the purposes of modelling, the planning system is treated in exactly the same way as other physical or environmental constraints. The model uses a rule based system to flexibly incorporate all of the factors that may prevent or add costs to development. Within this system, all constraints can have rules attached to them and these apply to all areas within the boundaries of the constraint. These rules can allow development, forbid development or add extra costs to development.

3.3.1 Example Constraints

Some examples of physical constraints and their impacts are as follows. Slope greater than 25 degrees may preclude industrial and commercial development and add $300 per square metre of gross floor area to residential development. A low density residential planning zone may allow rural residential and low density residential land use changes. A transport infrastructure charging zone may add $800 total cost to a detached residential unit and $600 to each attached residential unit.

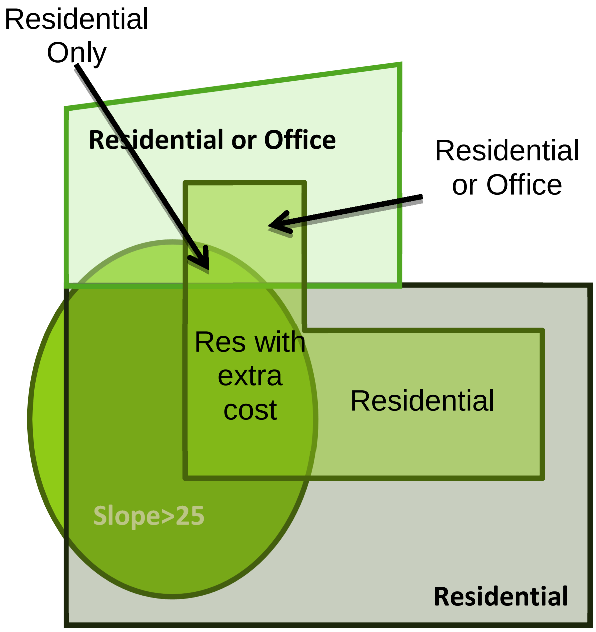
3.4 Combining layers

The system also allows the constraint layers to be specified completely independently of the cadastre – there is no need for constraint boundaries to be aligned with property boundaries. The system overlays all of the constraint layers with the property boundaries to find what is allowed on each section of the lot. This is particularly important in green-field areas, where the proposed development plan is likely to be more detailed than existing property boundaries. In some cases where there are very large Greenfield lots, these are automatically divided into smaller lots in a grid layout.

See the figure below for an example of how constraint layers are used for sub-lot level analysis.

1. Firstly, all of the constraints are combined and overlaid into a single layer (this improves performance)
2. The constraints are then overlaid with all property boundaries
3. Properties are divided into sub-lots, with a single set of rules applying to each sub-lot
4. All possible options for each sub-lot are generated
5. The areas in each option are recombined if possible

Figure 2 - a conceptual view of a parcel overlaid with planning and physical constraints.



So in the example we have 3 constraint layers. They are overlaid with each other and the property boundaries to give 4 sub lots. Given the rules and the sub lots, this gives 5 sub lot options. The sub lots that end up with identical land use are then recombined to give 2 aggregate options (either the whole block residential, or commercial plus residential).

3.5 Options evaluation

The key assumption in the evaluation of development options is that profitability is the key. The equation that is used to calculate the increased value to be gained by developing a lot is as follows:

$$M = P_n - P_o - B_n - D_n$$

M The marginal increase in value through land use change

P_n Market value of lot with new land use

P_o Market value of lot with old land use

B_n Construction cost of new land use

D_n Other development costs (approvals, infrastructure contributions etc)

The profit ratio is then the increase in value divided by the cost. The model has no particular preference for large development over small, as it is driven by profit ratio rather than total profit. It would be possible to include some economies of scale in development costs that will lead to increased profitability of large development.

3.6 Pricing model

The determination of property prices is obviously very complicated, and is influenced by supply and demand, local context, the value and condition of any improvements, socio-economic factors, local amenity and individual circumstances. For the purposes of modelling, information on most of these factors is simply unavailable. Even if it were available for the present situation, forecasting these factors into the future would be very difficult. The key assumption that we make is that the price of a lot depends purely on its size (both lots size and floor area), its land use and its location. This last factor is consistent with standard wisdom in real-estate – "the three most important things are location, location and location".

The current land use and lot size is obtained from the Digital Cadastral Database (DCDB) combined with council rates data. The total floor area of buildings is determined from building footprint surveys, augmented by assumed plot ratios that vary by current land use and total lot area. Note that we do not have any data on building age or quality.

The locational factors are contained in the various accessibility indicators obtained from the accessibility model. See below for more discussion on accessibility.

The pricing model is determined by looking at all recent property sales for each land use type and relating the sale price with the various lot and accessibility measures.

$$P = f(L, A, C)$$

P Market value of lot for a given land use

L Land area

A gross floor area of buildings

C accessibility by land use

The form of accessibility indicator used in the model has been shown to be consistent with a linear measure of locational utility, and so it is reasonable to assume that price is linearly related to accessibility. The relationship between price and size may have some non-linear aspects (price per square metre may be lower for large lots) but there was insufficient data to show this relationship and practical problems with implementing a non-linear relationship. So the final form of the pricing model is

$$P = (a_L + b_L C)L + (a_A + b_A C)A$$

Note that the price determined from this relationship is assumed to be the value of the existing use of the property. If there is a possibility of changing the use on the property (through reconfiguration or development) then developers will be able to foresee the potential profit from this and thus be willing to pay more for the lot than they would if it were unable to change from its current use. However the existing property owners are also likely to be aware of this, and so will likely expect to sell their property for a higher price. Thus the actual sale price of a property may be based, at least in part, on its potential future use rather than its existing use. This is difficult to capture in the model, and in a sense the overall formulation of the model makes it less important. The key evaluation indicator for a development option is the profit ratio for that option. In presenting this formulation we have focused on the perspective of a property developer, and said that the highest priority development is the one that returns most to the developer. If, in fact, part of that profit goes as a windfall gain to the current property owners through higher sales prices then that need not change the overall assumption. The proportion of the increased value that goes to the developer, and the proportion that goes to the existing land owner will depend on the negotiating skills of each party, and in fact in many cases the land owner is the developer.

This issue does present some problems for calibration, however, since there will be sales records with higher values due to unobserved development opportunities. We dealt with this issue by filtering out any high outliers in the regression process.

3.7 Construction costs

The construction cost model is quite simple – it simply uses unit rates per square metre of building by type. Any cost model can be simply incorporated. For South East Queensland, the costs used are in Napier and Blakeley (2010).

The model could be fairly easily extended to include holding costs of development (with some assumptions about approval times and construction times) but these are not included in the current application.

Infrastructure contributions can be very easily applied through the rule-based constraints, but these have not yet been included.

3.8 Accessibility

Accessibility is a term that has been applied to various different characteristics of the land use and/or transport system. Accessibility is always understood to be the ease of getting to something, and the various uses of the term differ in the types of things that can be reached. Most definitions of accessibility have the following properties.

- Accessibility is concerned with both the land use and the transport system, and provides an integrated way of measuring changes to either system.
- Accessibility considers the desirability of travel, not the actual travel that occurs. It is thus concerned more with the potential benefits of travel rather than just the cost, and accessibility can be determined for areas even when no one lives there.
- Accessibility is calculated with respect to a particular set of activities and a particular set of travel costs. Accessibility is TO an activity set FOR a particular market segment and BY a transport system.

Different individuals may experience different accessibility because their choice set may be different, their perception of the network costs may be different, and their preferences may be different.

Accessibility may be improved by decreasing the costs of interaction (by transport improvements or by more efficient land use distribution), or by providing new activities. Either of these changes will have a positive (or zero) effect on accessibility.

Because accessibility shows the benefit that a location can derive from the rest of the city, it can be increased by

- Adding more opportunities (shops, jobs, etc)
- Having closer opportunities
- Improving transport system (higher speed, lower cost)

The approach used to model accessibility in TransPosition's 4S Model is based on the micro-economic theory of random utility. This is an approach to modelling human behaviour that is based on a number of simple assumptions –

- In making a choice between a set of alternatives, it is possible to assign a value to each alternative (its utility) such that the alternative with the highest utility is preferred.
- The utility values cannot be exactly specified, due to variations in individual preference, unknown variations in the alternatives, and the fact that we do not have perfect knowledge of the alternatives.
- The utility values are best understood as random variables, where their values are specified by a probability distribution.
- The probability of any particular alternative being selected is equal to the probability that its utility is higher than all of the other alternatives.
- It is possible to state the expected utility of the full choice set, which is the expected value of the utility given that people always choose the alternative with the highest utility.
- The utility of the full set of alternatives can never be worse than the utility of the best alternative — it is never worse to have a wider range of choices. A corollary of this is that the utility of the choice set cannot be the average of the utilities of the individual choices, since the addition of a poor alternative will always lower the average utility.

There are many possible models that can be constructed from these assumptions, including the commonly used logit model, and (with some extra assumptions) gravity-type models. These model types can be used to construct accessibility measures, including the logit based Log-Sum, and the gravity model based Centrality. However both of these models require some fairly limiting assumptions about human behaviour that do not correspond very well with reality, and make it difficult to measure the benefits of localised accessibility, the effects of pricing, and the consequences of complex choice sets. TransPosition has developed a new approach to accessibility (as part of the Segmented Stochastic Slice Simulation model) that allows highly detailed analysis to be done within the context of a sophisticated and realistic behavioural model. This allows us to prepare lot-level estimates of accessibility, based on the lot-level distribution of activities around the city and a detailed representation of the multi-modal transport system.

In this formulation accessibility is equal to the benefit of being at another location, minus the cost of getting there, averaged out over a wide range of preferences (taken from random distributions using Monte Carlo sampling).

The full details of the accessibility modelling process, and plots showing the accessibility results, are beyond the scope of this document. Please contact TransPosition if you would like further details.

3.9 Allocation of demand

Summarising the processed already described, the Options Generation process produces a list of all permissible developments that could occur on each lot, and these are assessed in the Option Evaluation process (using the results of the Accessibility Model) to give an estimate of the likely profit margin from each sub-lot development. The final step is to convert these evaluated development options into a particular sequence of development over time.

To perform this process, we must start with “top-down” estimates of demand. These come from two sources. The residential demand comes from the population projection series for the model area. These give projected dwellings for each interval in the planning horizon, broken down by dwelling type (for example, attached and detached dwellings). The dwelling numbers are converted into building GFA requirements using standard rates for each dwelling type. The non-residential demand comes from employment estimates by industry. Again these are converted into GFA requirements by land use type using occupancy factors by industry (GFA/job). The occupancy factors were determined by taking the aggregate GFA by land use type in the base year model and dividing by employment estimates by industry from the ABS Journey to Work data.

For each forecast year we calculate the total increase in GFA required for each land use type, by subtracting the current totals from the future estimates. These may be understood as empty buckets of demand that need to be filled by a series of specific development options.

As stated earlier, the model assumes that the most profitable developments are likely to occur first, so all development options are placed into one big list and sorted by profitability. Starting at the top of the list, each option is allocated to its respective demand bucket. Once a development on a lot has been allocated, all other possible, but less profitable, options are removed. If the bucket is full then the development is rejected. This may mean that a less profitable development will be selected over a more profitable one for which there is insufficient demand.

Mixed use developments (such as a commercial development with ground floor retail) get allocated to more than one bucket. This can lead to a complication if there is demand for one of the mixed uses but not for another. There are two possible approaches to this – we could reject the whole development if any part of it is unnecessary, or we could accept the whole development. We have adopted the second approach, which works particularly well if the development rules allow different mixing proportions. For example, if the rules allow 100% commercial, 20% retail + 80% commercial or 100% retail then the model will choose the option that provides the best profitability without exceeding the top-level demand.

When development occurs on a lot it may trigger new demand – for example a detached house that is redeveloped as a commercial site will need to be replaced with another detached house somewhere else. The model deals with this by adding the existing use that is replaced by any new development to the top-down totals. This ensures that the final set of developed options will match the top-down demand estimates.

3.10 Outputs

An example of the output is shown in Figure 5. The output is typically a spatial layer of lots, in some cases divided into sub-lots, with a projected change of use and the timeline in which it is projected to change. This can be aggregated to any level required through spatial aggregation, for example.

3.11 Technical implementation

3.11.1 Data management

Data storage and retrieval is a critical part of the modelling process. This modelling framework required highly detailed spatial data and so throughputs can be very large. A single source of truth is required for base data, so it is important that no data is maintained in the application code itself. For large scale implementations a server-based data repository is required.

The model framework is independent of any particular data format. The existing model implementations use Microsoft SQL Server as a data repository. Spatial and non-spatial data is maintained in the form of tables with the OGC-compliant SQL Server geometry data type representing spatial information. All spatial information is saved and retrieved in the WGS84 projection with any required transformations occurring in the process of running the model.

3.11.2 Application code

Traditionally engineering and modelling applications were written in FORTRAN with large arrays stored as text files in the application folder. Programming and database technology has come a long way, but in many cases modelling applications have not. Modern programming environments permit fast execution, integrated development environments and automatic support for database integration and presentation.

This model is implemented as a .NET program written in the C# language. The technical architecture consists of discrete application classes, each performing defined tasks on a set of spatial or other data one by one. The application is able to run on any Microsoft Windows computer with the .NET framework installed.

3.11.3 Visualization

The spatial presentation of results can be done using any software package. TransPosition uses the Manifold GIS application which is able to link to external spatial data stores including Microsoft SQL Server. This approach enables the use of an inexpensive but powerful desktop GIS and mapping application with the benefits of robust server-side data storage and retrieval.

4 Benefits

This modelling framework has a number of benefits over traditional transport and land use models.

4.1 Cost and running times

The described model has several benefits over traditional models in computational cost.

4.1.1 Segmentation and reuse of processes

The model is implemented as a sequence with storage of results at each stage. For example, after the spatial layers describing the physical and zoning constraints are overlaid to produce a single, unified view of constraint combinations applying to each area, this is stored as a single spatial layer which can be reused in subsequent runs to avoid the need for rerunning the entire model.

4.1.2 Simplicity

As the model uses a simple land allocation process not involving auctions or any Monte-Carlo processes, the actual allocation of land use changes to years is a simple process. The entire process for allocating development options to time frames is extremely rapid once the development possibilities have been determined.

4.1.3 Projection times granularity control

The time spans over which land use changes can be applied is only dependent on the availability of data. For many planning agencies five year planning horizons are the norm, but precision down to single years or less would be achievable if demographic and employment forecasts were available at that level of detail.

4.2 Transport model independence

While the land use model is completely connected to a transport model providing information about locational accessibility, it is not tightly coupled to a single transport model. The accessibility of each location in the system is simply input data and could come from any source. In this way, the land use model is able to use existing well-developed transport accessibility models if they are available.

4.3 Planning consistency

The demand side of the land use model comes from demographic and employment projections. The output of the model will include population and employment projections that are, by definition, consistent with these numbers. This makes the model consistent with other aspects of planning.

5 Applications

The model has been successfully applied in a number of South East Queensland local government areas. A discussion of the implementation for the Brisbane City Council follows.

5.1 BUG 1.0

Brisbane City Council had an existing urban growth model (BUG 1.0), which Transposition developed in 2008 which dealt only with residential land uses. This model used a simple accessibility measure to rank the order of lots in which they were likely to be developed. That is, lots which enjoyed higher average accessibility were deemed likely to develop earlier than lots with a lower accessibility. Lots were then marked to be developed to the maximum density permitted by the planning scheme. This model has been in operation at BCC for more than two years.

5.2 BUG 2.0

After the successful implementation of BUG 1.0, a requirement was identified for an enhanced Brisbane Urban Growth Model that included commercial, retail and industrial land use types as well as residential uses (including mixed-use developments) and also included a more sophisticated construction and land pricing model. This became the basis of the Land Use Projections modelling framework discussed here.

5.3 Land use specification

The land uses were developed in consultation with planning staff at BCC. They corresponded to those referred to city planning. The land uses used in BUG 2.0 are:

- Residential: Attached
- Residential: Detached
- Retail: Shop
- Retail: Service/Trade
- Retail: Restaurant/Food
- Office
- Industry: Light
- Industry: Heavy
- Community: Health
- Community: Education
- Community: Other
- Transport (Roads/Rail alignment etc)
- Open Space
- Mixed use combinations of built form uses (e.g. Residential: Attached (60%) / Office (20%) / Retail: Shop (20%))

5.4 Constraints

The constraints impacting on development options were a combination of physical constraints planning constraints. Essentially the physical constraints preclude or limit development while planning constraints specify which type of land use is planned for each area. Physical constraints are shown in Figure 3, while planning constraints are shown in Figure 4.

5.5 Population and employment projections

The planning horizon for the South East Queensland Region is currently five year intervals from 2011 to 2031. These were taken as the projection years for the model.

5.5.1 Population control totals

The population forecasts come from the Queensland Government Population and Information Forecasting Unit (PIFU, 2011). The population of the Brisbane local government area was used as a control total for each of the projection years.

5.5.2 Employment control totals

The employment forecasts were taken from the The National Institute of Economic and Industry Research (NIEIR, 2011).

5.6 Outcomes

The BUG 2.0 is currently installed at the Brisbane City Council and is being used in the planning division to test many aspects of the city plan.

The model shows very clearly whether there is sufficient or insufficient capacity in the planning scheme for the population and employment projected to be required in the region.

As the model is based on economic factors and does not reflect central planning beyond the application of constraints on developments, it shows planners where the sequence of development may not be the same as envisaged.

An unexpected outcome of the model has been to identify areas where existing data is inadequate or incomplete.

6 Conclusions and recommendations

The modelling approach described here has been used in several projects with many successes. It has provided councils with consistent and defensible land use projections which are consistent with area wide population and employment projections, it has demonstrated the interaction between infrastructure, accessibility and land use changes over time and it has provided a means of testing the impact of regulatory and economic scenarios.

6.1 Areas for improvement

6.1.1 Existing land use data

The biggest single obstacle to providing accurate land use projections is the limitation of available data relating to existing land use. The experience of the projects discusses here is that the councils involved had (to varying degrees) very incomplete information regarding the exact land use existing in the region or city currently. The information available suggests land use mapping has been traditionally regarded as a broad scale exercise. With increased computational power now providing the opportunity to effectively map and project land use at the lot level there is now more reason for councils to maintain a more detailed and accurate map of building footprints and land use across the areas the cover.

6.1.2 Transport/land use modelling iteration

Currently the model determines the value of future land use according to a set of fixed accessibility values by location. This does not present too much of an issue in the case of relatively stable urban areas in which the overall development pattern is not likely to change, but presents more problems for regions in which substantial greenfield development or large scale change of use is projected to occur. TransPosition has developed plans for implementing an iterative approach in which for each successive development horizon year, a complete transport model would be run with the new land use set forming the basis of the population and employment values. The new accessibility values would then form the basis of the next land use change projections.

Figure 3 - Brisbane LGA Physical Constraints, based on data supplied by Brisbane City Council

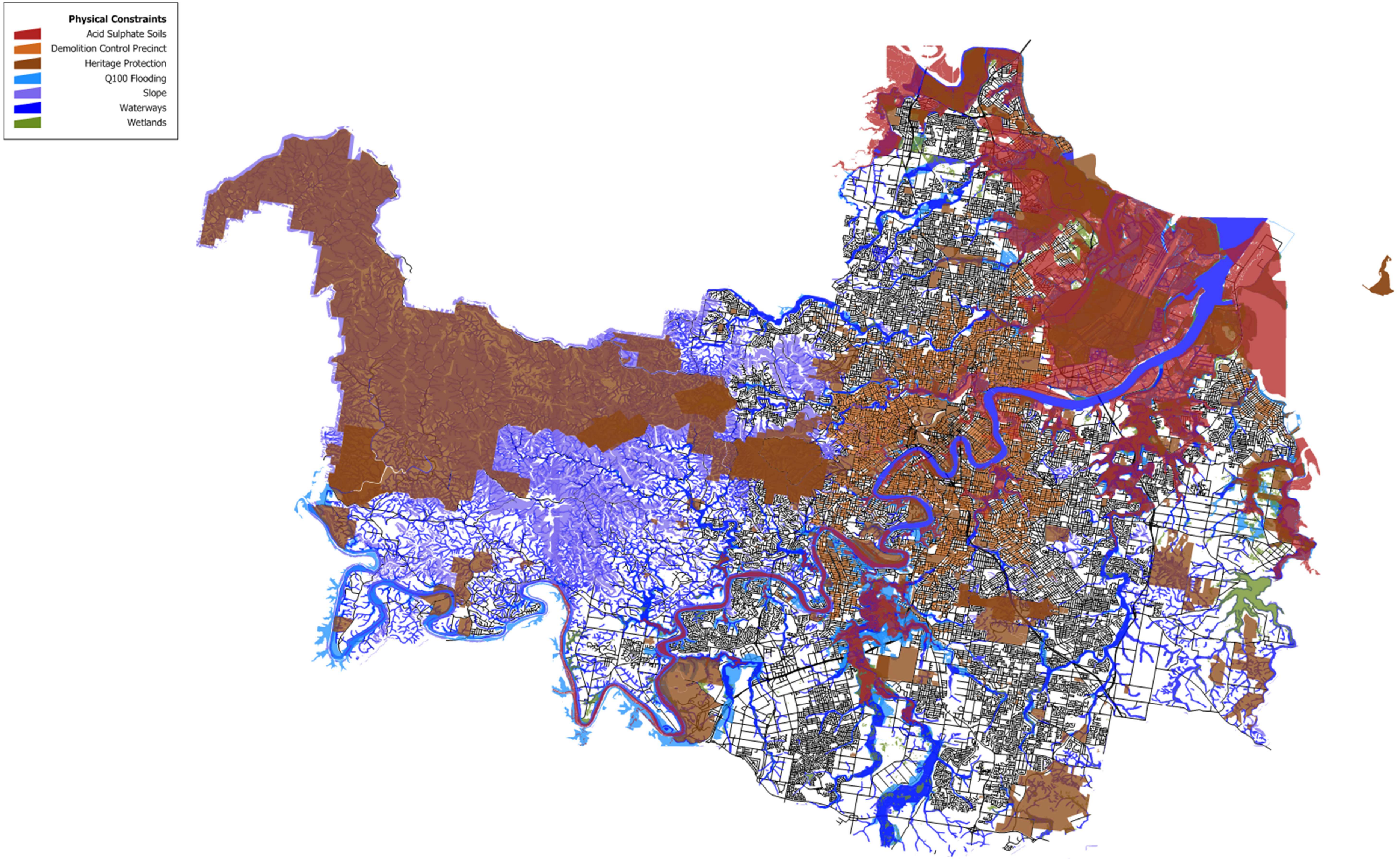


Figure 4 - Brisbane LGA Planning Constraints, based on data supplied by Brisbane City Council

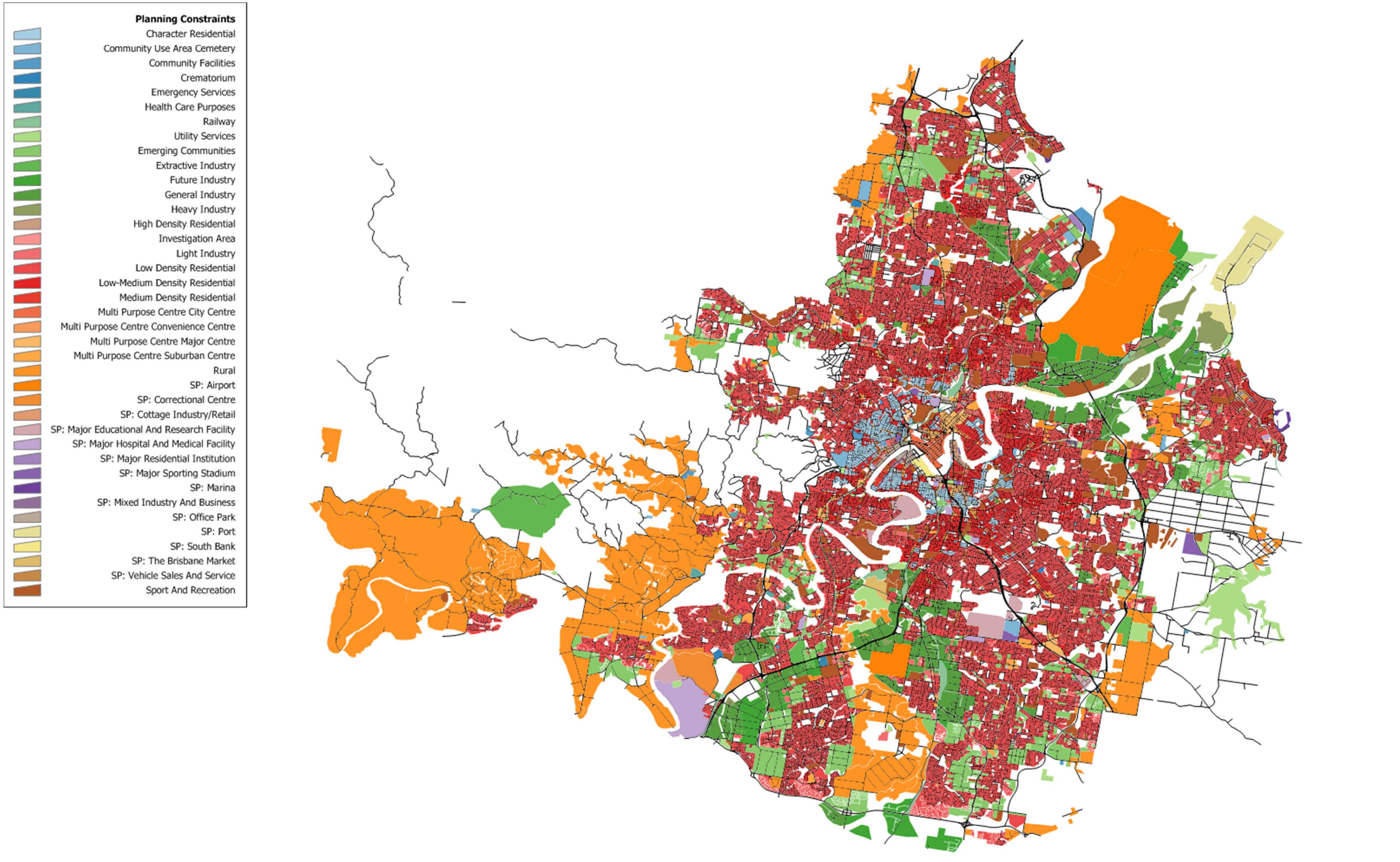


Figure 5 - Detail of Land Use Projection

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